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THE METAGABBROS AND RELATED ROCKS OF THE "YAKUNO COMPLEX" IN THE INNER ZONE OF SOUTHWEST JAPAN

By

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Page	Line	For	Read
3	23	"Hie"	"Hiei"
8	40	of basic rocks are generally	of basic rocks is generally
	41	hornblende gabbros	hornblende gabbro
9	20	these texture	these textures
12	17	, and is	, and are
13	Table 3-11(Y62-27b)	metagabbro, Ikemon,	metagabbro(pegmatitic), Ikemon,
17	(Fig. 3)	MgO_2	MgO
22	(Table 5)	$\overset{7}{\text{M-4}}\text{-60}$	$\overset{7}{\text{M-4}'}\text{-60}$
23	9	$(Al^{IV}+Fe^{+3}+\cdots\cdots$	$(Al^{VI}+Fe^{+3}+\cdots\cdots$
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	(Fig. 18)	(after Hashimoto, 1970)	(after Hashimoto et al., 1970)
37	23	p. 1—15.	p. 1—51.
38	6	minerals.	minerals and related phenomena.

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Isamu KOBAYASHI, Director

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CONTENTS

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Sachio IGI*

Abstract

The Yakuno Complex in the Maizuru structural belt, Southwest Japan, is mainly composed of metagabbros, granites, metamorphic rocks and associated ultramafic rocks, each of which also comprises the various kinds of rock facies. Of these rocks, metagabbro, called as "Yakuno Basic Rock", is extremely conspicuous among them. The rock classification of the Yakuno Complex is roughly shown as follows:

Yakuno Basic Rock
- Fine-grained hornblende gabbro
- Medium- or coarse-grained hornblende gabbro
- Pegmatitic hornblende gabbro
- Pyroxene-bearing hornblende gabbro
- Hornblendite

Maizuru Granites
- Adamellite
- Tonalite～quartz diorite
- Trondhjemite
- Granophyre, "felsite", etc.

Maizuru Metamorphic Rocks
- Biotite gneiss～schist
- Amphibolite

Associated Ultramafic Rocks
- Serpentinite
- Peridotite
- Pyroxenite

The successive relation between the basic and acid intrusive rocks is probably shown in the following order: hornblendite—pyroxene-bearing hornblende gabbro—medium- or coarse-grained hornblende gabbro—pegmatitic hornblende gabbro—granitic rocks.

The Yakuno Basic Rocks, based on the results of chemical analyses for the

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representative rock-specimens, are plotted in the areas of the alkali basalt and high alumina basalt series in an alkali and silica diagram (KUNO, 1966); on the other hand, the Maizuru Granites, in the area of tholeiite series.

Hornblendes remained unaltered in the basic or gabbroic rocks are selected for chemical analyses from hornblendite, biotite hornblende gneiss, fine-grained metagabbro, medium-grained or coarse-grained metagabbro and pegmatitic gabbro. Al^{IV} and Na atoms of hornblendes gradually decrease from hornblendite, through fine- and medium- or coarse-grained, to pegmatitic gabbro (Al^{IV} : 2.011~1.211 ; Na : 0.663~0.315) ; this order seems to correspond to that of succession of the formation of gabbroic rocks. These hornblendes from the Yakuno Basic Rocks are essentially considered to have been crystallized under the condition of high water vapor pressure, as described by YODER and TILLEY (1962), HERMES (1968 and 1970), NAKAMURA (1971) and others, during crystallization differentiation of the magma.

Ultramafic rocks in the Maizuru structural belt, somewhat different from those in other metamorphic terranes in Japanese Islands, might be mixed with those of dunite-harzburgite series derived from the deep-seated magma, and those of dunite-wehrlite series from the shallower, probably, gabbroic magma (KUNO, 1969).

It may be, therefore, considerable that the ultramafic rocks of dunite-harzburgite series was cumulated in the deep-seated magma generated under the geosynclinal basin in the Carboniferous to early Permian time, and then, the Yakuno intrusive rocks and their associated ultramafic rocks of dunite-wehrlite series were formed from gabbroic magma at the rather shallower depth. Following the rising of the liquids of the previous magma up to the lower crust or upper mantle, gabbroic magma have brought up to the present position, together with the fragments of the crystalline basements, along the fractural zones during the mountain-building movements at the late Permian or Triassic time.

I. Introduction

In the Inner Zone of Southwest Japan, the metagabbroic masses are mostly zonally distributed in the metamorphic terranes or structural belts. The so-called "Yakuno Basic Rocks" in the Maizuru structural belt are conspicuous among them, and are the most important members of the "Yakuno Complex" (HYOGOKEN, 1961). The "Yakuno Complex" is composed of various kinds of plutonic rock types, from acid to basic and probably to ultrabasic rock, and sometimes contains even the metamorphic rocks.

The author already summarized the geological relationships between this complex and the Permian or Triassic sediments in the Maizuru structural belt, in the explanatory texts of the geological sheet maps, "Maizuru" and "Ōeyama" (IGI et al., 1961 and 1965) and in the other papers (IGI, 1959 ; SHIBATA and IGI, 1966 ; IGI and MAEDA, 1967 ; IGI, 1967). Also, NAKAZAWA and his collaborators (NAKAZAWA and OKADA, 1949 ; NAKAZAWA, 1958; NAKAZAWA and SHIKI, 1958 ; NAKAZAWA, 1961 ; SHIMIZU, 1962 ; and others), who comprehensively studied the geology and paleontology of the upper Paleozoic and Triassic systems of the "Maizuru Zone", discussed the geotectonical significance of the intrusive emplacements of the Yakuno Basic Rocks and their related rocks. However, the detailed petrological descriptions on plutonic rocks of the Yakuno Complex have not been done yet.

In this paper, the author intends to present the comprehensive descriptions on the

Yakuno Comlex, especially on the Yakuno Basic Rocks, namely metagabbro, and further briefly to discuss the genesis of the igneous and metamorphic rocks in the lights of new data gained during the past decade.

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Any acknowledgement would be incomplete without expressing deep gratitude to Professor Dr. M. HUNAHASHI, Hokkaido University, for his many advices.

II. Historical Review

IGI (1959) and HASHIMOTO (1970) described the short history of geological and petrographical studies on the Yakuno Complex. It is summarized as follows.

About eight decades ago, YAMASHITA (1894) showed the intrusive rocks such as diorite, quartz dioritz, gabbro, olivine gabbro and gabbroic diorite, which are not uniform in their textures and occurrences, in the northern area of his 1 : 200, 000, geological sheet map "Hie". In the same time, KOCHIBE (1894 and 1895) also showed the similar rocks in his sheet maps, "Ikuno" and "Miyazu", scale, 1 : 200, 000. These rocks mentioned by them may correspond to those belonging to the "Yakuno Complex".

Subsequently, OGAWA (1897) studied the basic rocks, from the northern part of the Tamba terrane, in which the Yakuno Basic Rocks are certainly contained ; it was the first petrographical research on the Yakuno Complex. In 1925, TOMITA and SUGI proposed the hypothesis on the genesis of the basic rocks and their associated equivalents in the Ayabe and Yakuno districts, Kyoto Prefecture, after the theory of the gravitational differentiation of basaltic magma by BOWEN (1915 and 1928) ; that is, they depicted the occurrences of these rocks with the schematic model figures indicating that the basic or ultrabasic rocks occur in the lower parts of the terrain, and acid in the higher parts.

KOBAYASHI (1941) named these rocks as "Yakuno" intrusive rocks or "Yakuno" basic rocks, which were considered to have intruded at the stage of his "Oga-orogeny". It was the first that these basic intrusive rocks were called with local proper noun, "Yakuno ——".

MATSUSHITA (1950–51) described the zonal distribution of the "Yakuno intrusive rocks" in his "Geology of Kyoto Prefecture", and also stated that the western extension of their equivalents reaches so far to the southern parts of Okayama Prefecture. NAKAZAWA and his collaborators (see, previous chapter) studied the "Maizuru Zone", a synonym for the Maizuru structural belt, in about decade after the Second World War. However, their objectives of the researches were the structural geology, stratigraphy and paleontology of the Triassic and Permian systems, while the petrological studies on the igneous rocks were almost excluded. At that time, the researches on the crystalline basements found in the structural belts of the Japanese Islands, for examples, in the Kurosegawa structural belt (ICHIKAWA et al., 1956), were fashionable among the Japanese geologists. Then, the Maizuru (or Komori) metamorphic rocks, which are also the member of the Yakuno Complex, found by the author, were considered to be such a crystalline basement (KANO et al., 1959), and have aroused considerable attention of many Japanese geologists.....

III. Geological Environments

The Yakuno Complex is generally distributed in the Maizuru structural belt between the Chugoku and Tamba belts, Southwest Japan. However, it occurs also independently outside of the Maizuru structural belt, as seen in the eastern Chugoku belt or in the southwestern part of the Tamba belt, i. e. in the Kamigori district (Figure 1). The Chugoku belt is divided into the non- or slightly metamorphosed Paleozoic part and metamorphosed part ; the latter is named as the Sangun metamorphic belt, which is mainly composed of metamorphic rocks of the green-schist or glaucophanitic facies and also probably underlaid the Maizuru structural belt. The Tamba belt is constructed only of non- or slightly metamorphosed Paleozoic formations.

The Maizuru structural belt and the Chugoku belt or Sangun metamorphic belt are bounded by the fault zone. In the Maizuru district, the relations between these belts are exactly unknown, because of the wide distribution of the late Mesozoic igneous rocks and Tertiary volcanics and sediments. Presumably, the Sangun metamorphic rocks are concealed under these younger rocks. On the other hand, the Maizuru structural belt and the Tamba belt are also bounded by the fault. The Paleozoic formations of the Tamba belt near the boundary with the Maizuru structural belt are remarkably phyllitic, probably due to structural movements.

The Maizuru structural belt is constructed of the Permian (Maizuru Group) and Triassic (Nabae, Shidaka, Yakuno, Miharaiyama Groups, etc.), and the Yakuno Complex. They show zonal arrangements concordant to the general trend of the belt. The geological relationships between the Yakuno Complex and the Permian or Triassic sediments are structurally complicated. Generally, however, they are in contact with each other mainly by the sheared fault zones, though some members of the complex are often observed unconformably covered by Triassic sediments (Figure 2).

The Yakuno Complex generally occurs with zonal arrangement within the Permian formations or between the Permian and Triassic formations, although some of gabbroic and granitic rocks of the complex intrude into the Permian formations somewhere. In the Yakuno Complex itself, however, metagabbros are intruded by granitic rocks. Some of ultramafic rocks generally occurring along the faulting zones, intrude into not only these rocks, but the Permian and Triassic sediments.

Basaltic volcanic rocks and their associated dike- or sheet-formed "diabase", which are members of the so-called "Schalstein" intercalated into the Paleozoic formations, are excluded from the member of the Yakuno Complex.

The geotectonical situation of the Yakuno Complex in the Japanese Islands and its significance will be genetically discussed in the last chapter.

The geological successions associated with the Yakuno Complex are shown in the Table 1.

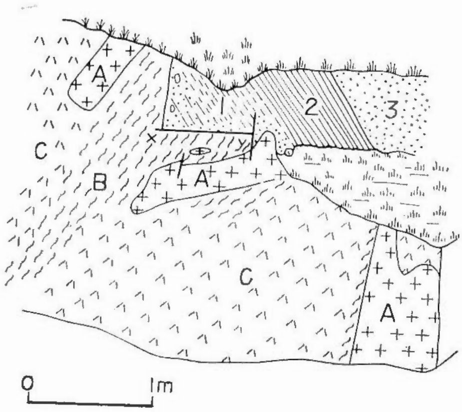


Figure 2. Relationship (Shidaka Unconformity) between the Maizuru Granite and Triassic Shidaka Group in the Shidaka district, Kyoto Prefecture, after NAKAZAWA, 1961.
1～3 : Shidaka Group.
1. Yellowish green fine-grained pebbly siltstone.
2. Purple shale.
3. Grayish green fine-grained sandstone.
A～C : Basements.
A. Leucocratic cataclastic granite (Maizuru Granite).
B. Schistose chlorite albite rock. } (Lower part of Maizuru Group)
C. Metadiabase ("Schalstein"). }
X-Y : Slipped part.

IV. Rock Classification and Occurrences

The Yakuno Complex is composed of the various kinds of rocks, which are gabbroic to granitic igneous rocks and higher grade metamorphic rocks such as biotite gneiss, and amphibolite, accompanied with a small amount of ultramafic intrusions. And porphyritic dikes are intruded into these rocks. They occur as intermingled composite bodies or masses, although they may be discriminated from each other when observed carefully even in the fields. A major part of the complex is, however, occupied by gabbroic varieties.

The gradual facies change in the rock-mass is observed especially in the metagabbroic rock-masses. Gabbroic rocks are petrographically composed generally of saussuritized plagioclase and hornblende as principal mineral composition, sometimes accompanied with clinopyroxene, and the change in grain-size of these minerals is also remarkable from fine-grained to coarse-grained, rather to pegmatitic, even within the scope of the handspecimen.

The rock classification of the Yakuno Complex is roughly shown as follows :

Table 1. Geological successions associated with the Yakuno Complex mainly in the Maizuru and Ōeyama districts, rearranged from explanatory texts on the geological sheet maps, "Maizuru" and "Ōeyama" (IGI et al., 1961 and 1962).

Geologic age		Formation		Igneous rock	Metamorphism, crustal movement and others
Quaternary	Holocene	Alluvium			
Quaternary	Pleistocene	Terrace deposits			Upheaval
Plio-Pleistocene		Volcanic formation	(Shallow sea deposits)	Andesite Basalt	Upheaval
Pliocene				Andesite (Basalt, rhyolite)	
Miocene		Volcanic formation and shallow sea deposits	"Green tuff" formations		(Volcanism) Geosyncline
Paleocene~ Cretaceous		Volcanic formation	"Late Mesozoic igneous formations"	Granite Rhyolite Andesite	(Plutonism) Contact metamorphism (Volcanism)
Jurassic					Upheaval (Tectonic movement)
Triassic	Upper	Inland sea deposits	Nabae Group Arakura Group Miharaiyama Group		
Triassic	Lower		Yakuno Group Shidaka Group	ULTRAMAFIC ROCKS GRANITE } YAKUNO INTRUSIVES	Tectonic movement
Permian	Upper	Shallow sea deposits	Maizuru Group	GABBRO } YAKUNO INTRUSIVES	Upheaval (Sangun metamorphism)
Permian	Lower	Deep sea deposits	Tamba Group	Basic volcanic rock	Geosyncline (Sangun metamorphism)
Pre-Permian			MAIZURU or KOMORI METAMORPHIC ROCKS		

Yakuno Complex

1. Slightly metamorphosed igneous rock	
(a) Basic rock :	
Gneissose hornblende gabbro (metagabbro)	
Fine-grained....	
Medium- or coarse-grained....	Yakuno Basic Rock
Pegmatitic....	
Pyroxene-bearing hornblende gabbro	
Hornblendite (with or without clinopyroxene)	
(b) Acid (granitic) rock :	
Adamellite	
Tonalite～quartz diorite	
Trondhjemite	Maizuru Granite
Albitophyre, granophyre, granite porphyry,	
"Felsite"	
2. Metamorphic rock	
Biotite gneiss～ banded gneiss	
Biotite schist	Maizuru or Komori
Amphibolite	Metamorphic Rocks
Other related metamorphic rocks	
3. Associated ultramafic rock	
Serpentinite	
Dunite	
Pyroxene peridotites	
Clinopyroxenite	

Here, although the ultramafic rocks are excluded from the regular members of the Yakuno Complex and treated as associated rocks because of the difference of their occurrences from the other rocks, they are possibly one of the members, judging from their genetic relations which will be described in the last chapter.

All of these rocks of the complex, excepting ultramafic rocks, are contained in several zoned masses, some of which are intermittently zoned, with various dimensions, elongated parallel to the general trend of the Maizuru structural belt.

Gneissose hornblende gabbro has always foliated structure (*Plates* I–2, 3 and II–1), probably of igneous flow structure in origin, general trend of which is also approximately in accord with that of the direction of the belt. The rhythmic banded layers of basic and acid rocks, parallel to the trend, with width of about 0.1m, are occasionally observed in some masses (*Plate* I–1). Such acid rocks are presumably injected into the basic rocks as small sheets concordant with the gneissose structure of basic rocks. Not only the facies changes of gabbroic rocks mainly in grain-sizes are remarkable, but also the rocks are altered by the effects of the violent shearing stress into the cataclastic rocks, usually accompanied with the low grade metamorphic minerals, some of which might be formed by the effect at that time, such as prehnite, pumpellyite, epidote, albite, and calcite, so that, sometimes, these rocks are not able roughly to be distinguished from each other in the fields. In places, prehnite rocks also occur as leucocratic vein, about 5 cm in width, accompanied with quartz, calcite, white mica, etc., especially along the shearing parts in gabbroic rocks as well as in other rocks of the

Yakuno Complex.

The granitic rocks, named Maizuru Granites, occur as rather large mass only in the type locality of the Maizuru district ; most of them, however, are intruded into the Yakuno Basic Rocks or Permian sediments as dike- or stock-formed small masses. It is also difficult to discriminate one rock-facies of granites from others, as given in the previous list, in the field, because of their conspicuous alterations as well as observed in gabbroic rocks. It is especially notable that these igneous rocks, both of basic and acid, have not given any remarkable thermal effects to the country rocks.

Metamorphic rocks, called as the Maizuru or Komori Metamorphic Rocks, are generally distributed only in the restricted areas, namely, in the Sugesaka and Komori districts. Besides, the metamorphic rocks similar to them occur also in the basic or acid igneous rocks as small xenolithic (or Schlieren-like) inclusions. It is, however, uncertain whether they are the same as the Maizuru or Komori Metamorphic Rocks or not. They are, in any events, considered to have been derived from the crystalline basements of the Japanese Islands or to be some fragmental varieties of higher grade parts of the Sangun metamorphic rocks, judging from only the mineral assemblage without any diagonistic minerals, even any polymorphs of Al_2SiO_5, as will be described in the following chapter.

Small masses of ultramafic rocks occur along or in the faulting or shearing zones which are sometimes the boundary between Paleozoic or Mesozoic sediments and the Yakuno Complex. They are also found along the faulting zones in the Yakuno Complex itself. Most of the rocks are conspicuously serpentinized and it is difficult to investigate their characteristics of original peridotites. However, the relict minerals such as olivine and pyroxenes, are rarely preserved. Considering from the assemblages of the relicts, their original peridotites are of dunite and of either harzburgite or wehrlite. Besides, it is also interesting that many of clinopyroxenite are alone kept unaltered.

Dikes of porphyrite, about 1.00 m in width, are intruded into all sorts of the above-stated rocks in almost all parts of the area. They are rather fresh and are able to be easily distinguished from the other rocks by their characteristic porphyrite texture after plagioclases, though they are slightly altered. They may be products during the volcanic activities in the late Mesozoic age.

V. Petrography

As already mentioned in the previous chapter, the Yakuno Complex contains the different sorts of rocks, i.e. not only igneous rocks, being basic to acid, but metamorphic rocks. Moreover, their rock-facies are very variable even in the same rock type. In this chapter the outlines of the rocks and their facies changes are petrographically described.

V. 1 Igneous rocks

a) Basic rock.....Yakuno Basic Rock

The most abundant facies of basic rocks are generally **medium- or coarse-grained hornblende gabbros** (*Plate* III-3) which is composed mainly of saussuritized plagioclase and hornblende. Diopsidic clinopyroxene is rarely found occurring as relicts (?) in hornblende. These minerals are 0.3 mm to 1.5 mm in length and about 1.0 mm in width. Some optical properties of hornblende are given in Table 7. Those of other minerals were not accurately estimated, and An % values (An 50~60) of plagioclase are also not so exact because these minerals have been altered more or less. The characteristic gneissose structure in these rocks is due to the parallel arrangement of hornblende. Secondary minerals such as prehnite, pumpellyite, calcite, sericite, albite, and epidote, found in all over the gabbroic equivalents, are presumably formed by the low-grade regional metamorphism or deuteric hydrothermal alteration during the later stage of their emplacements (IGI, 1967). The medium- or coarse-grained hornblende gabbro is often associated with fine-grained and pegmatitic facies and sometimes gradually changes to other facies.

Fine-grained facies of the hornblende gabbro occurs in the medium-grained facies frequently with thin banded structure. It consists mainly of the same minerals as those of medium- or coarse-grained facies. The grain-sizes of plagioclase and hornblende are about 0.1 mm and 0.1~0.2 mm in length, respectively. It is also mosaic (*Plate* III-1) and not ophitic, in some cases nematoblastic or lepidoblastic, in texture. Plagioclase is mostly cloudy and altered into "saussurite", and its An % is about 60 (50~70), though the optical determination is difficult. Hornblende is rather fresh and green in colour, rarely light brown as well as that from medium-grained facies, though its optical properties and chemical composition will be discussed in the following chapter. The accessory and secondary minerals are zircon and iron ore, and chlorite, epidote, sphene, prehnite, pumpellyite, albite, white mica, calcite, quartz, etc., respectively. Judging from these texture, some of the fine-grained type of gabbros are considered to be inclusions derived from amphibolites of higher grade metamorphic rocks.

Pegmatitic facies of hornblende gabbro occurs as pool-like lens or vein in the medium-grained facies, measuring 1.00 ~ 0.10 m or less both in width and length (*Plate*I-4). It consists distinctively of large crystals of hornblende and plagioclase, measuring about 1.0 cm in length. Plagioclase is also found as subhedral large crystal, great parts of which are altered into aggregates of prehnite or "saussurite".

The field occurrence and appearance of clinopyroxene-bearing hornblende gabbro are similar to those of medium-grained hornblende gabbro. It is composed mainly of saussuritized plagioclase, brown hornblende and diopsidic clinopyroxene, some of which occur also as relict in hornblende (*Plate* III-4), accompanied with the same accessory and secondary minerals as those in other basic rocks. The gneissose structure by parallel arrangement of hornblende is also found.

Pyroxene gabbro, called "true gabbro" by IGI et al. (1961), is exposed along the fault zone at the Umezako district of Ayabe-city and occurs as a small mass accompanied with some ultramafic rocks. It is rather massive and homogeneous. And it is mainly composed of altered plagioclase, chloritized orthopyroxene and clinopyroxene accompanied with ilmenite and magnetite. Plagioclase is about 0.5 mm in width and is very clouded; its An 70 is not so exact value. Diopsidic clinopyroxene ($2V\gamma=60°$) is about 0.8 mm in width with diallagic partings on (100).

Hornblendite occurs rarely as ultramafic facies, with somewhat xenolithic appearance, in the medium-grained gabbro. It is composed almost of brown hornblende (*Plate* III-2), with or without a small amount of diopsidic clinopyroxene and saussuritized plagioclase. This rock is presumably of specifically accumulated part of brown hornblendes in the medium-grained facies at the early stage of the formation of the hornblende gabbro.

b) Granitic rock (Maizuru Granites)

The Maizuru Granites, named by IGI, KURODA and HATTORI (1961), occur not only as rather large mass, but as small dike-formed mass, and, their rock facies are also lithologically variable. They had ever been called "sheared granites" or "older granites" on account of discrimination from the late Mesozoic granites in Southwest Japan. All the rocks are protoclastic and cataclastic in texture (*Plate* IV-2), and some of dike- or stock-formed ones, porphyroclastic.

The granitic mass in the Maizuru district, where is type locality for the Maizuru granites, occurs in a batholithic dimension, and often includes diabasic xenoliths. The granitic rocks are composed mainly of plagioclase, quartz, potassium feldspar, chloritized biotite and rarely muscovite, and are equigranular, measuring about 0.5 mm in grain-sizes of minerals. Potassium feldspar is perthitic and often shows micrographic intergrowth with quartz. And it is variable in quantities of minerals ; accordingly, these rocks show also various facies, from adamellitic to trondhjemitic or tonalitic. Green hornblende is not common and rarely found only in some marginal parts of granitic mass. Accessory minerals are zircon, apatite, allanite and iron ore. And alteration products are epidote, chlorite, sericite, sphene, prehnite, etc.

Granitic rocks of the small mass are likewise very variable in the lithologic characters. Such varieties of rock facies as quartz diorite (-porphyrite) (*Plate* IV-1), granite porphyry, quartz porphyry, albitophyre, and "felsite", are recognized ; however, all these rocks are mainly composed of quartz, and plagioclase, with or without potassium feldspar, in accompany with chloritized biotite. And their altered products are also chlorite, epidote, sphene, albite, prehnite, calcite, etc. The gneissose structure is also often observed. The variation of these rock facies is probably due to the differences of the physical or chemical conditions during differentiation and solidification of magma.

The probable succession of the formation of igneous rocks, from the above-mentioned facts, is synoptically shown as the following order : hornblendite—pyroxene-bearing hornblende gabbro—medium- or coarse-grained hornblende gabbro—pegmatitic hornblende gabbro—granitic rocks. The mineral associations of these igneous rock types are summarized in Table 2.

V. 2 Metamorphic rock (Maizuru or Komori metamorphic rock)

The metamorphic rocks, appearance of which is somewhat distinctive, occur typically both in the Sugesaka and Komori (Ōe) districts. They are composed mostly of amphibolites and biotite gneiss and a small amount of marble. Their metamorphic grade is rather higher, possibly of amphibolite facies, judging from their original mineral assemblages.

Amphibolites are predominantly nematoblastic or mosaic in texture (*Plates* IV-3, 4), and are composed mainly of green hornblende, plagioclase, a small amount of quartz, biotite and garnet, the last one of which is usually not regular ; diopsidic clinopyroxene are rarely found, especially in the Komori district. And many secondary alteration products such as epidote, zoisite, carbonate, albite, pumpellyite, prehnite, are also common.

The xenolithic amphibolites in hornblende gabbro are very similar to them in the mineral assemblage and textures (*Plate* II-3). So that, both might have been derived from the identical deep-seated metamorphic rocks.

Biotite gneiss with banded structure (*Plate* II-4) is composed mainly of plagioclase, quartz, potassium feldspar, biotite and garnet (Igi and Maeda, 1967). These minerals are variable in grain-size and in quantity ; however, black parts of the bands contain relatively a large amount of biotite and garnet, while, white parts, of quartz and plagioclase. Pota-

Table 2. The mineral associations of igneous rock types in the Yakuno Complex.

	Rock type (excluding associated ultramafic rocks)	Principal mineral association (excluding accessory or secondary products)
Yakuno Basic Rocks	Gneissose hornblende gabbro	
	Fine-grained	altered plagioclase-brownish green hornblende (An50~70) *
	Medium~coarse-grained	altered plagioclase-green light green hornblende, or some one, brown hornblende (An50~60)
	Pegmatitic	altered plagioclase-light green hornblende (An40~60)
	Pyroxene-bearing hornblende gabbro	altered plagioclase-brown hornblende-clinopyroxene (An60~70)
	Hornblendite	brown hornblende-clinopyroxene (2Vγ : 60°±)
	Pyroxene gabbro	altered plagioclase-clinopyroxene (An70±) (2Vγ : 60°±)
Maizuru Granites	Adamellite	quartz-plagioclase-potassium feldspar-biotite (-muscovite) (An15~20)
	Tonalite or quartz diorite	quartz-plagioclase-biotite-hornblende (An20±)
	Trondhjemite	plagioclase-quartz-biotite (An=20~30)
	Albitophyre	albitic plagioclase-quartz- (biotite) (An10±)
	Granophyre~granite porphyry	quartz-plagioclase-potassium feldspar-biotite (An10~20)
	"Felsite"**	quartz-feldspars (-biotite)

* Not only An % values of plagioclase were not exactly estimated, but values for optical properties of other minerals were scarcely measured, because these minerals are altered, more or less, excepting amphiboles, some for which are given in Table 7.

** "Felsite" is used as a synonym with unclassified hypabyssal acid rock.

Table 3. Chemical compositions for rocks of the Yakuno Complex.

	1	2	3	4	5	6	7	8	9	10
	O-309	M-4-60	Y63-6	Y62-1	Y62-80	M-286	M-312	Y62-25	Y62-34	Y62-27a
SiO_2	64.67	45.72	48.17	46.00	45.58	42.52	50.60	49.95	46.41	47.15
TiO_2	0.37	0.43	1.49	1.78	1.63	1.33	2.02	1.28	3.32	0.78
Al_2O_3	16.58	23.63	16.27	15.49	16.33	16.62	12.17	15.48	14.32	18.50
Fe_2O_3	0.84	1.92	2.40	2.69	2.39	5.40	3.62	2.18	4.22	1.36
FeO	5.64	4.58	6.68	9.34	9.99	8.16	6.14	6.61	9.59	5.39
MnO	0.10	0.17	0.17	0.24	0.28	0.21	0.35	0.21	0.30	0.19
MgO	2.38	6.43	7.22	8.11	8.80	8.43	9.07	8.85	5.92	8.80
CaO	2.60	8.54	9.27	9.86	8.48	9.05	7.73	7.14	7.45	11.32
Na_2O	2.64	2.43	3.26	2.66	2.57	3.30	3.87	3.42	3.37	2.30
K_2O	1.00	2.32	0.97	0.63	0.28	0.58	0.90	0.74	0.64	0.33
P_2O_5	0.04	0.11	0.32	0.09	0.26	0.29	0.33	0.14	0.37	0.02
$H_2O(+)$	2.07	3.00	2.82	1.67	2.80	3.36	2.37	2.96	3.18	3.15
$H_2O(-)$	0.56	0.38	0.44	0.52	0.19	0.48	0.40	0.53	0.37	0.41
Total	99.49	99.66	99.48	99.08	99.58	99.73	99.57	99.49	99.46	99.70
Analyst	TSKL	H. K.	TSKL	Ditto	Ditto	H.K.	Ditto	TSKL	Ditto	Ditto

1. (O-309) Biotite gneiss, Komori, Ōe-cho, Kyoto Prefecture.
2. (M-4-60) Amphibolite, Sugesaka, Ayabe City.
3. (Y63-6) Biotite amphibolite, Sugesaka, Ayabe City.
4. (Y62-1) Metagabbro, Seki, Maizuru City.
5. (Y62-80) Medium-grained meta-(hornblende) gabbro, Shimoyakuno, Kyoto Prefecture.
6. (M-286) Coarse-grained metagabbro Mutsushi, Ayabe City.
7. (M-312) Medium- or coarse-grained metagabbro, Sugesaka, Ayabe City.
8. (Y62-25) Fine-grained hornblende metagabbro, Oyogi, Maizuru City.
9. (Y62-34) Schistose fine-grained metagabbro, Hoshihara, Ayabe City.
10. (Y62-27a) Medium-grained metagabbro, Ikeda, Maizuru City.

ssium feldspar with microcline structure is usually small in quantity, and in some cases is not found at all. Of these minerals, especially, feldspars are dirty or cloudy and have been also altered into secondary minerals such as sericite, epidote, prehnite, etc.

In the Kawahara district, eastern part of the area of 1:50,000 sheet map "Ōeyama", hornblende biotite gneiss is exposed with mylonitic appearance in the sheared zone between the Paleozoic formations. It is surely gneissose in texture, though mostly cataclastic, and composed mainly of plagioclase, quartz, biotite and hornblende, rarely in company with potassium feldspar showing quadrille structure due to two sets of microscopic lamella twinning. Accessory minerals are garnet, apatite and iron ore; alteration products are chlorite, white mica, sphene, prehnite, etc. (Igi et al., 1965).

Schistose crystalline limestone occurs as small lenses intercalated in the biotite-bearing amphibolite at the southeastern part of Odahara in the Komori (Ōe) district. It is composed only of calcite accompanied with a small amount of chlorite, quartz and sericite.

Granitic rocks with mylonitic or porphyroidal appearance occur with biotite gneiss both in the Sugesaka and Komori (Ōe) districts. The rocks are granoblastic and gneissose in texture, partly protoclastic or cataclastic, and is often mistaken for biotite gneiss, because of their similarity in the field appearance. They are composed mainly of quartz, plagioclase (An 10~20), potassium feldspar with microcline structure and

11	12	13	14	15	16	17	18	19	20
Y62-27b	Y62-78a	Y62-78b	Y63-37	M-237	Y63-2	Y63-5	M-41	Y62-35	Y63-50
47.22	41.69	46.96	44.12	41.00	70.02	76.99	77.30	60.58	35.93
0.48	3.67	1.01	0.23	1.11	0.27	0.13	0.16	0.11	0.09
21.49	15.49	19.72	18.12	13.10	13.33	12.57	13.59	17.17	2.73
0.86	3.49	1.44	1.92	3.44	0.92	0.76	0.65	0.32	10.54
2.80	10.88	7.40	4.53	7.93	3.21	0.47	0.23	0.50	2.44
0.12	0.44	0.28	0.13	0.22	0.13	0.03	0.02	0.03	0.23
4.52	6.39	5.08	10.49	13.48	0.98	0.20	0.33	0.93	34.62
15.21	10.14	8.91	13.44	13.05	2.31	0.25	0.45	16.97	0.03
2.41	2.37	3.47	1.34	1.62	4.32	4.77	5.28	0.38	0.20
0.28	0.36	0.59	0.83	0.18	0.78	2.71	0.78	0.08	0.01
1.02	1.19	0.36	0.01	0.40	0.06	0.03	0.04	0.01	0.01
3.14	2.88	3.32	3.80	3.92	2.17	0.59	0.93	2.46	11.72
0.20	0.46	0.48	0.45	0.58	0.35	0.15	0.36	0.28	0.88
99.75	99.45	99.02	99.41	100.03	98.85	99.65	100.12	99.82	99.43
TSKL	Ditto	Ditto	Ditto	H.K.	Ditto	Ditto	H.K.	TSKL	Ditto

11. (Y62-27b) Coarse-grained metagabbro, Ikemon, Maizuru City.
12. (Y62-78a) Fine-grained schistose meta-(hornblende) gabbro, Shimoyakuno, Kyoto Prefecture.
13. (Y62-78b) Medium-graind meta-(hornblende) gabbro, Shimoyakuno, Kyoto Prefecture.
14. (Y63-37) Pyroxene-bearing hornblende gabbro, Hijiman, Hyogo Prefecture.
15. (M-237) Pyroxene-bearing hornblendite, Umezako, Ayabe City.
16. (Y63-2) Quartz diorite, Kutami, Maizuru City.
17. (Y63-5) Graphic granite, Okimihama, Maizuru City.
18. (M-41) Granite (Maizuru-granite), Makabe, Okada, Kyoto Prefecture.
19. (Y62-35) Leucocratic vein, Takakura, Ayabe City.
20. (Y63-50) Serpentinite, Ōhara, Okayama Prefecture.

Abbreviation for Analysts : TSKL……Tokyo Sekitan-Kobutsu Laboratory
H. K. ……Hajime KURASAWA

biotite. Accessory minerals are zircon, garnet, apatite and iron ore ; prehnite vein is also predominant. The rocks are presumable to be a kind of synkinematic granitic intrusions during the metamorphism, judging from their occurrences and microscopical texture.

V. 3 Associated ultramafic rocks

The large masses in considerable dimension, such as Ōeyama or Sekinomiya ultramafic bodies, are excluded in this paper, because of their emplacements in the Sangun metamorphic terrane on the northern outside of the Maizuru structural belt (IGI and ABE, 1969), although they correspond to "ultramafic masses of Type I in the "Maizuru zone" after KUROKAWA (1972).

Most of the ultramafic rocks in the belt occur as the rather smaller masses in the faulting or shearing zones developed in the Paleozoic or Mesozoic formations and the Yakuno Complex. They belong to Kurokawa's Type II (1972). The exception is the Oshima body which is relatively large in dimension. Although the Oshima body was already studied by HIRANO (1969), other masses are still going to be studied by several investigators (KUROKAWA, IGI, KURODA et al., in preparation). The present author here describes the petrographical outline of them only in brief.

Table 4. C.I.P.W. norm compositions and Crystallization Indexes after POLDERVAART and PARKER (1964), recalculated from chemical compositions (Table 3) for the Yakuno Complex, by means of computer "FACOM 270-20/30" through kind arrangements of Dr. K. WADATSUMI.

	1	2	3	4	5	6	7	8	9	10
Q	32.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C	6.68	1.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	5.91	13.71	5.73	3.72	1.65	3.43	5.32	4.37	3.78	1.95
Ab	22.34	17.13	27.59	22.51	21.75	18.61	32.75	28.94	28.52	19.46
An	12.22	41.72	26.90	28.47	32.20	28.82	13.18	24.70	22.06	39.18
Lc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ne	0.00	1.86	0.00	0.00	0.00	5.05	0.00	0.00	0.00	0.00
Ac	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wo-Di	0.00	0.00	6.90	8.11	3.22	6.00	9.70	3.95	5.18	6.88
En-Di	0.00	0.00	4.43	4.77	1.86	3.94	7.05	2.63	3.04	4.67
Fs-Di	0.00	0.00	2.01	2.94	1.21	1.64	1.75	1.03	1.90	1.68
En-Hy	5.93	0.00	3.21	1.49	7.52	0.00	9.53	12.71	9.75	4.94
Fs-Hy	9.24	0.00	1.45	0.92	4.87	0.00	2.36	4.97	6.08	1.78
Fo	0.00	11.22	7.24	9.77	8.78	11.95	4.20	4.70	1.37	8.62
Fa	0.00	4.97	3.61	6.63	6.27	5.47	1.15	2.02	0.94	3.43
Mt	1.22	2.78	3.48	3.90	3.47	7.83	5.25	3.16	6.12	1.97
He	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Il	0.70	0.82	2.83	3.38	3.10	2.53	3.84	2.43	6.31	1.41
Ap	0.09	0.26	0.76	0.21	0.62	0.69	0.78	0.33	0.88	0.05
H_2O	2.63	3.38	3.26	2.19	2.99	3.84	2.77	3.49	3.55	3.56
C. I.	16.47	53.11	46.23	50.07	50.52	49.38	39.42	44.23	37.01	61.59

These rocks were mostly altered into serpentinite, including rodingitic xenolith, and have little or no relicts of original minerals such as olivine and pyroxenes. According to the assemblages of few relict-minerals and their textures, the main types of the ultramafic rocks are presumable to be of dunite, harzburgite, wehrlite, lherzolite and rarely websterite. Smaller mass of clinopyroxenite is exclusively more fresh, not altered into serpentinite.

The ultramafic rock series in the Maizuru structural belt are somewhat different from those of other metamorphic terranes (RESEARCH GROUP of PERIDOTITE INTRUSIONS, 1967) ; that is, ultramafic rock series from the sheared zone between the Maizuru and Tamba belts belong, generally speaking, to dunite-harzburgite series; however, they are accompanied with lherzolite and rocks of dunite-wehrlite series. According to the results of studying of RESEARCH GROUP of PERIDOTITE INTRUSIONS (1967), there is characteristically only one ultramafic series for one metamorphic or structural belt, i.e. dunite-wehrlite series for the Sambagawa metamorphic belt and dunite-harzburgite series for the Sangun or the Kamuikotan metamorphic belt ; from these facts, multi-ultramafic series for the Maizuru structural belt might be exceptionally different from the others. That is, ultramafic rocks in the Maizuru structural belt might be mixed with those of dunite-harzburgite series derived from the deeper-seated magma, and those of dunite-wehrlite series, from the shallower, probably, gabbroic magma depicted by KUNO (1968).

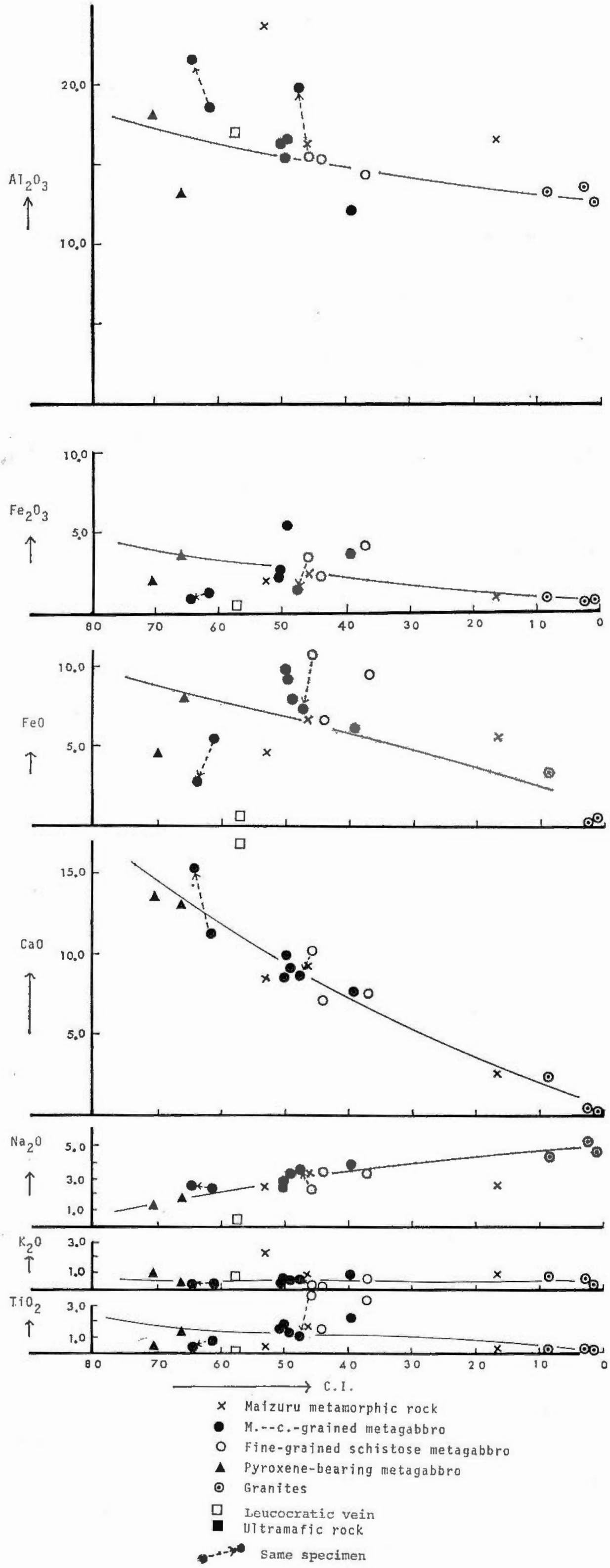
11	12	13	14	15	16	17	18	19	20
0.00	0.00	0.00	0.00	0.00	35.31	38.19	42.25	28.62	0.00
0.00	0.00	0.00	0.00	0.00	2.93	1.49	3.33	0.00	2.39
1.65	2.13	3.49	4.91	1.06	4.61	16.02	4.61	0.47	0.06
20.39	20.06	29.36	8.20	3.38	36.56	40.36	44.68	3.22	1.69
46.99	30.57	36.49	40.98	27.94	6.68	0.81	2.00	44.91	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	1.70	5.59	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9.30	5.22	2.13	9.76	14.38	0.00	0.00	0.00	3.14	0.00
6.38	2.88	1.10	7.07	10.08	0.00	0.00	0.00	2.32	0.00
2.19	2.14	0.97	1.79	3.09	0.00	0.00	0.00	0.53	0.00
0.97	3.87	1.51	0.00	0.00	2.44	0.50	0.82	0.00	29.85
0.33	2.88	1.34	0.00	0.00	4.93	0.08	0.00	0.00	0.00
2.74	6.42	7.04	13.35	16.46	0.00	0.00	0.00	0.00	39.50
1.04	5.27	6.90	3.71	5.56	0.00	0.00	0.00	0.00	0.00
1.25	5.06	2.09	2.78	4.99	1.33	1.10	0.34	0.46	8.35
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00	4.78
0.91	6.97	1.92	0.44	2.11	0.51	0.25	0.30	0.21	0.17
2.42	2.82	0.85	0.02	0.95	0.14	0.07	0.09	0.02	0.02
3.34	3.34	3.80	4.25	4.50	2.52	0.74	1.29	2.74	12.60
64.23	46.08	47.43	70.32	66.08	8.57	1.16	2.57	57.60	

VI. Petrochemistry

Although the Yakuno Complex contains various kinds of rocks, as mentioned in the previous chapter, the specimens for chemical analysis are selected principally from the Yakuno Basic Rocks and Maizuru Granites. Twenty analyses of the selected specimens and their C.I.P.W. norms with crystallization index (C.I.) after POLDERVAART and PARKER (1964) are given in Tables 3 and 4, respectively. Specimens of Nos. 1 to 3, are of metamorphic rocks, and those of No. 19 and 20 are of prehnite-bearing leucocratic vein and serpentinite, respectively. These were also selected just to obtain the representative chemical properties of their respective rock types.

C.I.-variation diagram for the Yakuno Complex is shown in Figure 3. The points for various oxides of the Yakuno Basic Rocks and the Maizuru Granites are roughly arranged on smooth curves which seem to indicate the general trends of the crystallization differentiation of igneous rocks.

The plots in the triangular diagram of $FeO+Fe_2O_3\times0.9$, Na_2O+K_2O and MgO are shown in Figure 4. The points especially for the basic rocks are dispersed in a wide range, and they are not comparable to that of the Daly's calc-alkaline series. There is the problem in it why such dispersion occurs. It is probable that the rem-



20.0
10.0
Al_2O_3
10.0
5.0
Fe_2O_3
80
70
60
50
40
30
20
10
0
10.0
5.0
FeO
15.0
10.0
5.0
CaO
5.0
3.0
1.0
Na_2O
3.0
1.0
K_2O
3.0
1.0
TiO_2
80
70
60
50
40
30
20
10
0
C.I.
Maizuru metamorphic rock
M.--c.-grained metagabbro
Fine-grained schistose metagabbro
Pyroxene-bearing metagabbro
Granites
Leucocratic vein
Ultramafic rock
Same specimen

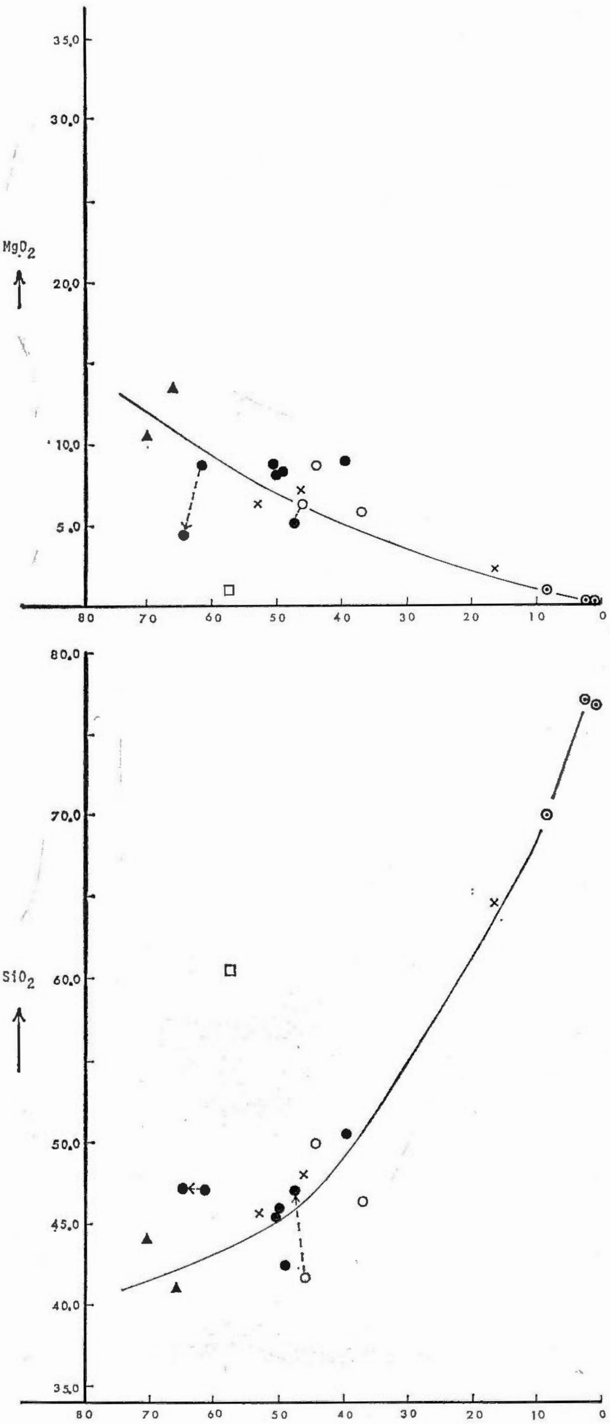


Figure 3. C-I (Crystallization Index) variation diagrams for the Yakuno Complex, after POLDERVAART et al., 1964. Point for ultramafic rock is not included in these diagrams.

arkable migrations of the elements in the process of magmatic differentiation have caused, or the large amounts of deep-seated rocks such as basic metamorphic rocks in the Yakuno Basic Rocks have been somewhat concerned.

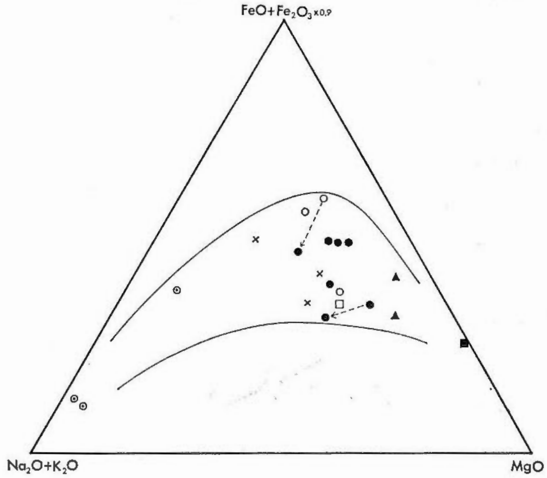


Figure 4. F–M–A diagram for various rocks of the Yakuno Complex. Symbols correspond to those in Figure 3.

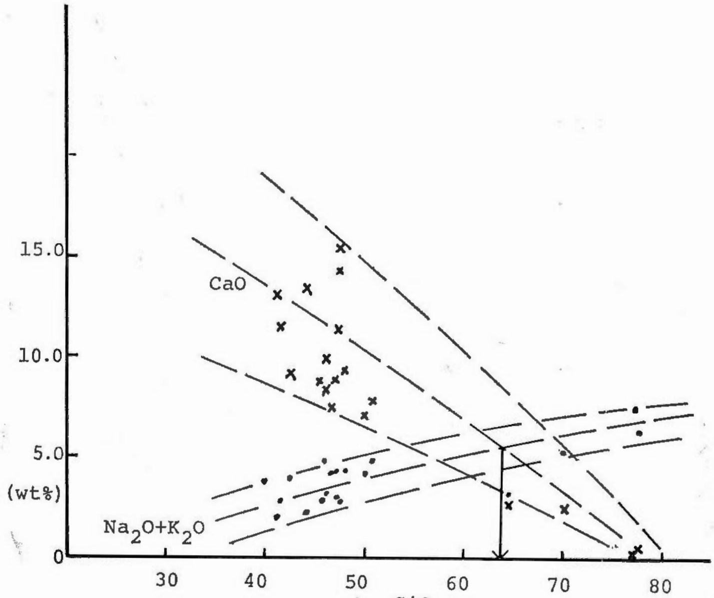


Figure 5. Variation diagram for Na_2O+K_2O and CaO against SiO_2 (wt%) fromthe various rocks of the Yakuno Complex, according to the alkali-lime indices after PEACOCK (1931) .

Abscissa : weight percentage of SiO_2

Ordinate : weight percentage of CaO (cross) and Na_2O+K_2O (solid circle).

The plots of Na_2O+K_2O and CaO versus SiO_2 (wt. %), giving alkali-lime indexes after PEACOCK (1931), are shown in Figure 5. The alkali-lime indexes for the Yakuno Basic Rocks and the Maizuru Granites are also very variable, estimating from about 54 to 72 and mean value, 63, that is, the Yakuno basic and acid igneous rocks, so far as the results are concerned, belong to calc-alkaline or rather calc-rock series. As shown in the figure, however, any point is not plotted in the area between 50 and 64 weight percents of SiO_2, so that, in this case, estimated results for alkali-lime indexes may be unavailable.

In Figure 6 the relationship among normative anorthite, albite and orthoclase is

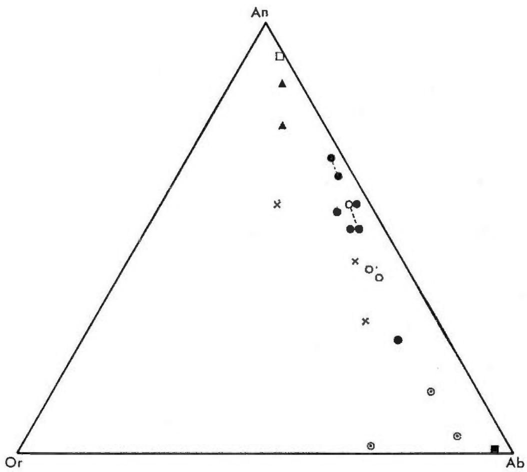


Figure 6. Triangular diagram showing the relationships among normative anorthite, albite and orthoclase of the various rocks of the Yakuno Complex. Symbols correspond to those in Figure 3.

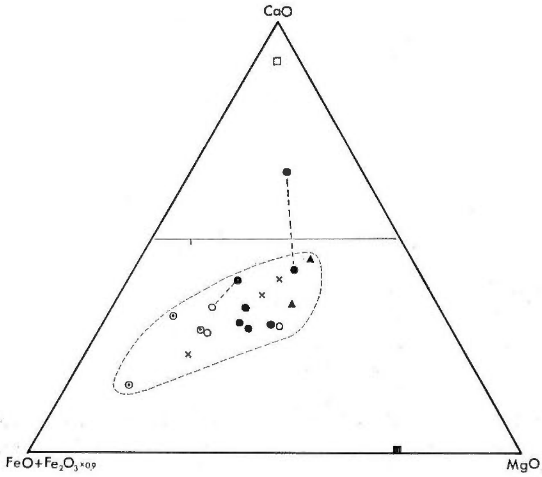


Figure 7. Total FeO-MgO-CaO diagram for the rocks of the Yakuno Complex. Symbols correspond to those in Figure 3.

shown ; it is likely that there is a tendency of gradual change in normative compositions from pyroxene-bearing gabbroic rock, higher in An content of plagioclase, to granitic rock, higher in Ab content, although Or content, within 10 %, is little changeable.

Figure 7, total FeO-MgO-CaO diagram, shows that the points for the Yakuno basic and acid rocks are plotted within an area bounded by dotted line, excluding exceptions for ultramafic rock, leucocratic vein and one basic rock (No. 11), and generally proportions of total FeO for CaO and MgO increase, though these for metamorphic rocks are also included in the diagram.

Figure 8 is a diagram showing the relationship of alkali and silica for the recent volcanic rocks, given by KUNO (1966). It is noteworthy that in this diagram the

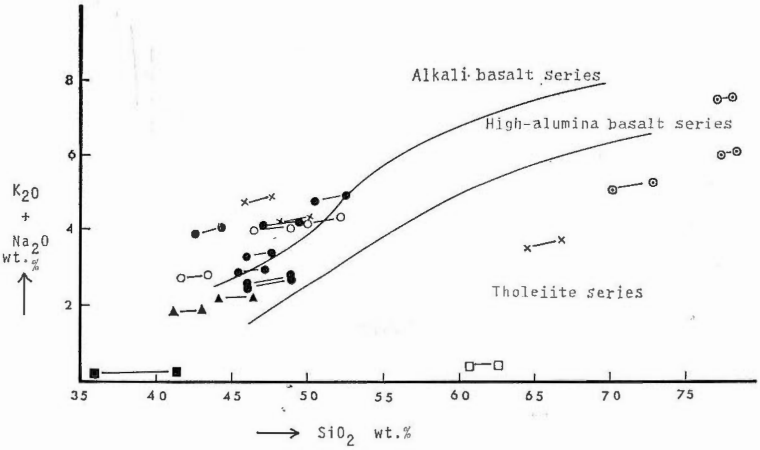


Figure 8. Relation diagram of alkali and silica for the rocks of the Yakuno Complex, after KUNO (1966). Symbols correspond to those in Figure 3.

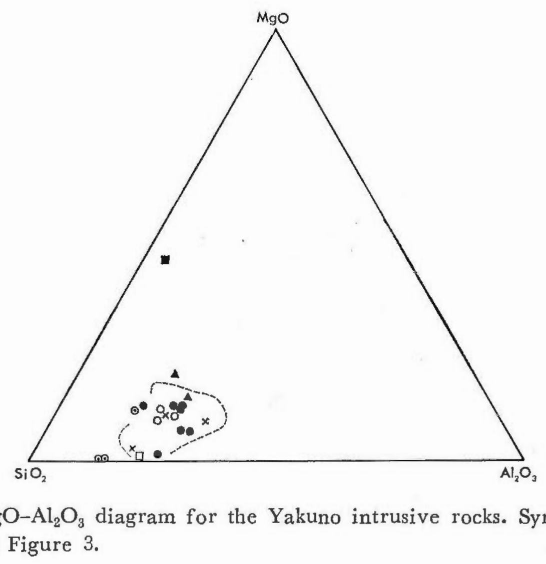


Figure 9. SiO_2–MgO–Al_2O_3 diagram for the Yakuno intrusive rocks. Symbols correspond to those in Figure 3.

Yakuno Basic Rocks are plotted in the areas of the alkali basalt and high alumina basalt series, whereas the Maizuru granitic rocks, in the area of the tholeiite series. Here, two points tied by a line are for the identical specimens ; left is original and right is recalculated one as anhydrous basis. As shown in this figure, the compositions of the Yakuno intrusive rocks are variable also in Kuno's rock series classification. It may be considered that the differentiation process of the primary magma of the Yakuno intrusive rocks was very complicated.

SiO_2– MgO– Al_2O_3 diagram for the Yakuno intrusive rocks is illustrated in Figure 9. The points for the Yakuno Basic Rocks are almost plotted in the same area bounded by curved lines, as limited the distributions of compositions of the green rocks from the Kanto mountains after Uchida (1967) and volcanic rocks from the Paleozoic Chichibu Group after Tanaka (1970). The facts concerning Figure 9 may support that the chemical compositions of the Paleozoic basic volcanic rocks are considerably similar to those of the Yakuno intrusive rocks on their genetic affinities.

VII. Mineralogy of Amphiboles

Most of the primary minerals of the rocks of the Yakuno Complex, especially those of the granitic rocks, are more or less altered into the secondary minerals ; however, hornblende have remained unaltered in the gabbroic rocks, notwithstanding the reason is not yet clearly explained. Hornblende is contained in the all over the facies of the Yakuno Basic Rocks, and in the basic metamorphic rocks, and then is also presumable to be the most important rock-forming mineral for the explanation of the genesis of the Yakuno Complex.

For chemical analyses seven samples of hornblendic amphiboles were chosen from the some representatives of the hornblende-bearing rocks ; that is, hornblendite, biotite hornblende gneiss (amphibolite), fine-grained metagabbro, medium- or coarse-grained metagabbro, pegmatitic metagabbro. Hornblendes have been separated through Franz isodynamic magnetic separator from finely crushed host rocks, and then they were purified by heavy liquids.

The analytical results and their atomic ratios, estimated on the anhydrous basis of 0=23.000, are presented in Table 5.

In all hornblendes, Si atoms are almost close to 6 or over 6, (5.989 to 6.788). The deficiency of Si for Z group of amphibole's structural formula is filled by Al, together with Fe^{+3} only in the sample of No. 4, coarse- or medium-grained metagabbro. Total iron is very variable, showing a range from 0.936 to 2.519 and Mg is also variable, from 2.204 to 3.952. Whereas Ca is restricted in rather narrow range, from 1.757 to 1.917.

Analyzed hornblendes are plotted on Ca– Mg– Fe triangular diagram, Figure 10, showing that chemical variation of hornblende is principally controlled by Mg– Fe substitution, while Ca remains constant.

Al^{IV} and Na atoms gradually decrease from hornblendite, through fine-grained and medium- or coarse-grained, to pegmatitic gabbros (Al^{IV} : 2.011～1.212, Na : 0.663～0.315). This order may correspond to the succession of the formation of gabbroic rocks. These facts are probably reflected in the several diagrams which will illustrate some chemical relationships among hornblendes from the basic igneous rocks.

Composition fields of calciferous amphiboles from metamorphic rocks of basic and intermediate compositions of the world are illustrated in Figure 11, after Shido (1958).

Table 5. Chemical compositions of amphiboles from the Yakuno Complex and atomic ratios estimated on the anhydrous basis of O=23.000.

	1 M-237	2 O-271	3 Y62-34	4 M-312	5 Y62-27(M)	6 Y62-27(P)	7 M-4-60
SiO_2	40.10	41.70	42.38	43.25	46.54	47.22	42.25
TiO_2	1.88	1.19	1.35	2.07	0.92	1.17	1.59
Al_2O_3	12.11	12.85	10.81	7.37	9.54	8.73	10.03
Fe_2O_3	4.00	3.56	5.94	4.05	3.68	3.65	5.89
FeO	9.12	4.51	14.74	10.68	8.27	9.16	7.62
MnO	0.20	0.11	0.37	0.47	0.32	0.32	0.40
MgO	14.97	18.26	9.86	15.30	16.32	15.15	15.32
CaO	11.81	12.32	10.98	11.65	11.44	11.76	11.58
Na_2O	2.29	2.02	1.28	1.19	1.20	1.13	1.75
K_2O	0.12	0.28	0.57	0.36	0.04	0.04	0.60
$H_2O(+)$	3.43	2.38	1.40	3.49	1.32	1.54	2.33
$H_2O(-)$	0.30	0.15	0.16	0.36	0.10	0.08	0.42
Total	100.33	99.33	99.84	100.24	99.69	99.95	99.78
Analyst	H.K.	Ditto	K.M.	H.K.	K.M.	Ditto	H.K.
Atomic Ratio (O=23)							
Si	5.989	6.056	6.357	6.492	6.671	6.788	6.256
Al^{IV}	2.011	1.944	1.643	1.508	1.329	1.212	1.044
Al^{VI}	0.120	0.256	0.269	0.000	0.282	0.266	0.007
Fe^{+3}	0.449	0.389	0.670	{(0.202) 0.254	0.396	0.394	0.656
Ti	0.211	0.129	0.152	0.233	0.099	0.126	0.177
Fe^{+2}	1.139	0.547	1.849	1.340	0.991	1.101	0.943
Mn	0.025	0.013	0.047	0.059	0.038	0.038	0.050
Mg	3.331	3.952	2.204	3.422	3.486	3.245	3.381
Ca	1.889	1.917	1.764	1.873	1.757	1.811	1.837
Na	0.663	0.568	0.372	0.346	0.333	0.314	0.502
K	0.022	0.051	0.109	0.068	0.007	0.007	0.113
$\frac{100 \times Mg}{Mg+Fe^2+Fe^3+Mn}$	67.37	80.64	46.21	64.83	70.98	67.92	67.21

1. From clinopyroxene-bearing hornblendite with igneous texture, Umezako, Ayabe City.
2. From hornblendite with metamorphic texture, Fukōtōge, Miyazu City.
3. From fine-grained metagabbro, Hoshihara, Ayabe City.
4. From coarse- or medium-grained metagabbro, Sugesaka, Ayabe City.
5. From medium-grained metagabbro with pegmatitic parts, Ikemon, Maizuru City.
6. From pegmatitic part in medium-grained metagabbro, Ikemon, Maizuru City.
7. From biotite hornblende gneiss, Sugesaka, Ayabe City.

Abbreviation for Analysts : H.K.……Hajime KURASAWA ; K.M.……Kenjiro MAEDA

All points for amphiboles from the Yakuno Basic Rocks are plotted in or near the field of common hornblende. Also, Al^{VI} and Al^{IV} relation diagram is shown in Figure 12. All points plotted for amphiboles from the Yakuno Basic Rocks are, as it is a matter of course, out of the fields of the alkali-amphiboles after MIYASHIRO (1957).

Figure 13, alkalies-Al^{IV} diagram, is a diagram showing well the chemistry of calcium rich amphiboles (DEER et al., 1963). The values of Na+K are directly proportional to the Al^{IV}, that is, they increase from hornblendite, through fine-grained and medium- or coarse-grained gabbros, to pegmatitic gabbro.

Figure 14, (Al^{IV} + Fe^{+3} + Ti) -Al^{IV} diagram, is also a diagram showing the chemistry of calcium rich amphiboles (DEER et al., 1963). From this diagram, it is clearly recognized that there is no relation between the increase of Al^{IV} and the amount of (Al^{VI} + Fe^{+3} + Ti).

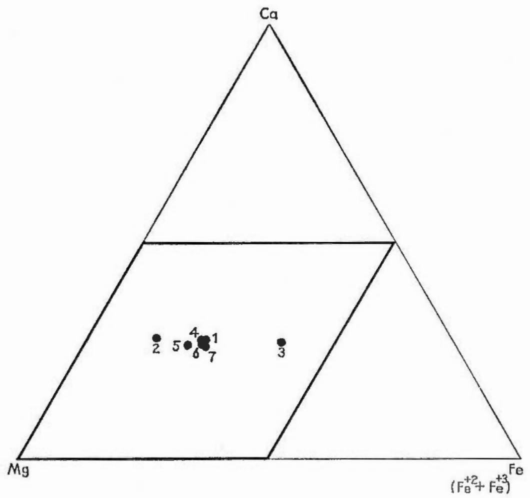


Figure 10. Ca-Mg-Fe triangular diagram for amphiboles from the Yakuno Complex.

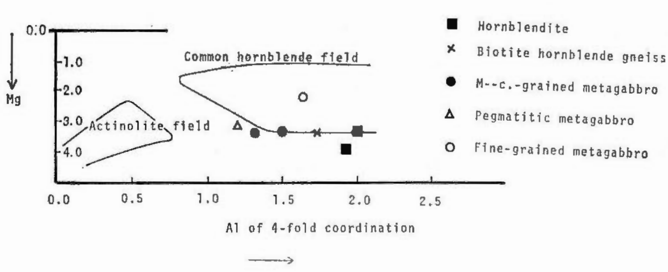


Figure 11. Composition field of calciferous amphiboles from metamorphic rocks of basic and intermediate compositions of the world, after SHIDO (1958).

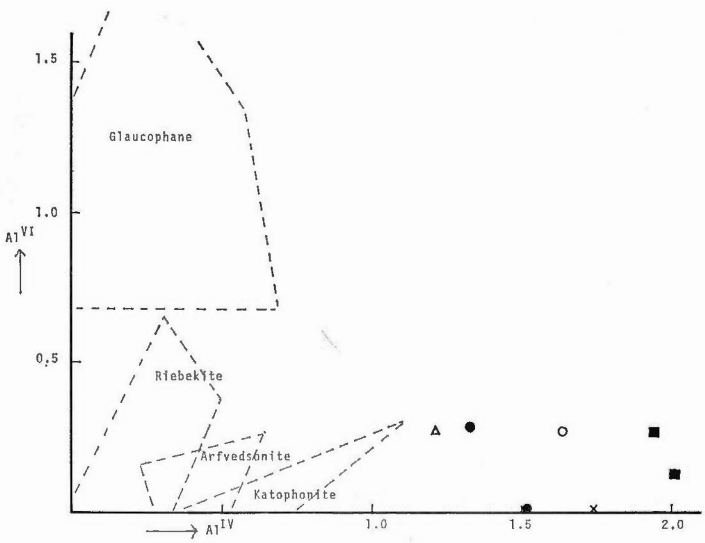


Figure 12. Al^{VI} and Al^{IV} relation diagram for alkali-amphiboles, after MIYASHIRO (1957). Symbols correspond to those in Figure 11.

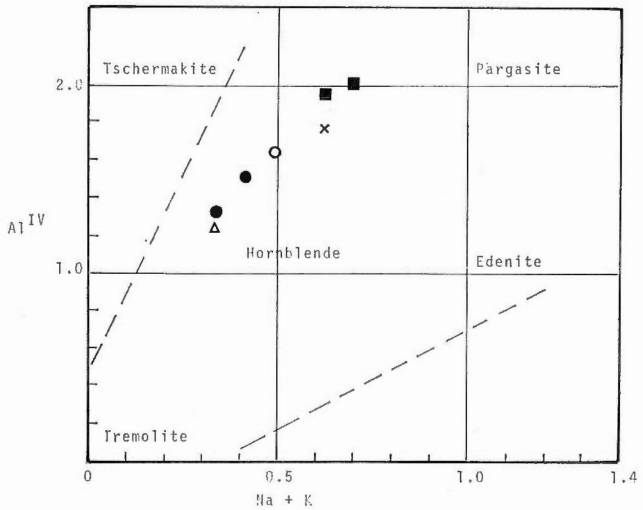


Figure 13. Chemical variation diagram for the calcium rich amphiboles expressed as the numbers of (Na+K) atoms and Al^{IV} per formula unite, after DEER et al. (1963). Symbols correspond to those in Figure 11.

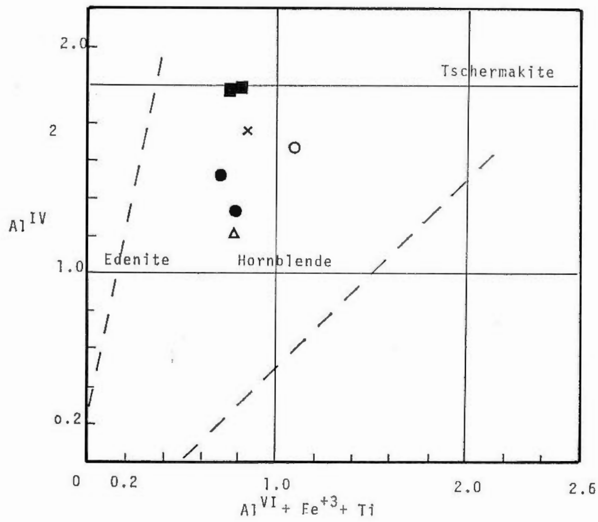


Figure 14. Chemical variation diagram for the calcium rich amphiboles expressed as the numbers of ($Al^{VI}+Fe^{+3}+Ti$) and Al^{IV} atoms per formula unit, after DEER et al. (1963). Symbols correspond to those in Figure 11.

Table 6. Molecular proportions of the analyzed hornblendic amphiboles, reestimated after SHIDO's method (1958).

	1	2	3	4	5	6	7
Tremolite	4.616	4.572	4.876	3.564	5.100	5.556	5.000
Tschermakite	0.911	1.033	1.503	0.730	1.087	1.057	1.063
Edenite	0.685	0.619	0.371	0.414	0.340	0.191	0.615
Sodatremolite			0.220			0.260	
Calcium-edenite	0.320	0.408		0.768	0.100		0.104
Cummingtonite	1.084	1.148	0.724	2.044	1.172	0.684	0.860
Titanoamphibole	0.422	0.258	0.304	0.466	0.198	0.252	0.354
Glaucophane							
Total	8.038	8.038	7.998	7.986	7.997	8.000	7.996

The chemical analyses are recalculated for their molecular proportions after SHIDO's method (SHIDO, 1958), and are presented in Table 6. According to this recalculation, molecule of glaucophane is wholly not present ; of soda-tremolite presents only for the two samples Nos. 3 and 6, which do not contain calcium-edenite molecule. It is noteworthy that tschermakite molecule of the amphibole from fine-grained gabbro, which is probably of the earliest product of gabbroic rock types, though it might be metamorphic xenolith, is the highest in value ; and edenite and cummingtonite molecules, from pegmatitic gabbroic rocks, which is probably the product of the latest stage also of the gabbroic rock types, are the lowest.

Table 7. AlⅣ atomic ratios and some optical properties of hornblendic amphiboles from the Yakuno Basic Rocks (2V : over α).

	Al^{IV} (1.0 – 2.0)	2V (70 – 80 – 90)	$c\hat{}Z$ (10 – 20 – 30)	Refractive index (γ) (1.65 – 1.70)	Axial colour (X............Z)
1 (M-237)	•	76	27	1.678	light green...brown
2 (O-271)	•	88	23	1.655	light brown...light green
3 (Y62-34)	•	78	22	1.677	light brown...deep green
4 (M-312)	•	77	24	1.664	very light brown... light green
5 (Y62-27 m)	•	81	21	1.669	v. light brown... light green
6 (Y62-27 p)	•	82	18	1.667	v. light brown... light green
7 (M-4-60)	•	80	25	1.669	colourless-light green... green

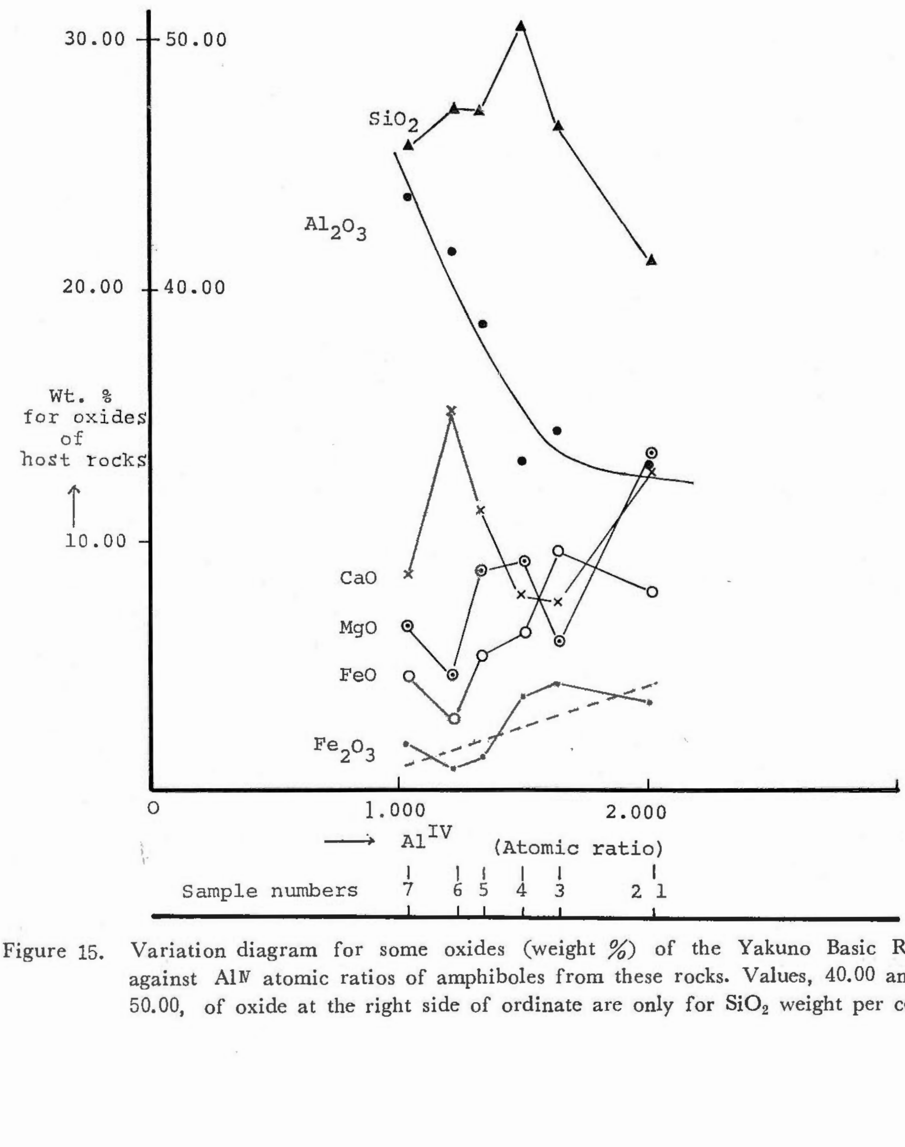


Figure 15. Variation diagram for some oxides (weight %) of the Yakuno Basic Rocks against AlⅣ atomic ratios of amphiboles from these rocks. Values, 40.00 and 50.00, of oxide at the right side of ordinate are only for SiO_2 weight per cents.

In Table 7, Al^{IV} atomic ratios are summarized together with some optical properties for their comparisons. Also, a variation diagram showing the relationships between Al^{IV} atomic ratios of amphiboles and some oxides (weight percent) of their host rocks is illustrated in Figure 15. It is interesting that Al_2O_3 percents of host rocks decrease with the increasing of Al^{IV} atomic ratios of amphiboles. Other oxides do not show such correspondence. These facts may suggest that the amount of Al^{IV} is rather concerned with the chemical compositions of their host rocks, and with the modal compositions of plagioclase and amphibole. It seems that volume percentages of plagioclase increase with changes of rock facies, from fine-grained gabbro to pegmatitic one, though not estimated actually. If so, the amount of Al^{IV} may be still concerned with the succession of the formation of gabbroic rocks, under somewhat different conditions of the temperature and pressure.

VIII. Genetic Considerations

VIII. 1 Origin of hornblende-bearing metagabbro

The hornblende-bearing gabbroic rocks had been considered by some geologists probably to be one of products during deutric alteration, a kind of autometamorphism, of early crystallized minerals in magma (SEDERHOLM, 1916), especially at the high temperature hydrothermal sub-stage of post-magmatic stage (SHAND, 1927). That is, at the later stage of magmatic differentiation, clinopyroxene was wholly or mostly altered into hornblende by introduction of the higher temperature-water vapor.

Besides, some investigators have thought that hornblende gabbros of Japanese metamorphic or tectonic belts, e.g. Kamuikotan and Hidaka belts, are products associated with metamorphic recrystallization such as amphibolitization based on the conception of "Petroblastase" concerning the structural movements during regional metamorphism (HUNAHASHI, 1957 ; WATANABE, 1965 ; SAKO et al., 1971 ; HASHIMOTO, S., unpublished ; and others). Their hypothesis is considered to have promising possibilities towards the future development ; however, it has not yet enough convinced other investigators.

Well, about decade ago, YODER and TILLEY (1962) have stated in the abstract of their paper on origin of basalt magma by experimental investigations, as follows : ".. ... the field of stability of basalt is drastically reduced in the presence of water, and amphibolite is produced. The melting of amphibolite takes place over a much great range of temperature than basalt. At 10 kb. water pressure the beginning of melting of amphibolite closely approach that of granite. Partial melting of amphibolite may yield anorthositic liquids having a relatively low anorthite content at exceptionally low temperatures. Eclogite itself is not stable in the presence of water and gives place to amphibolite or pyroxene hornblendite. Magma which crystallized to basalt, gabbro, or eclogite must have a low water content at the time of crystallization". Figure 16 shows general melting relation in alkali basalt from Hual alai, Hawaii, under water pressure—projection of natural alkali-basalt-water system— (after YODER and TILLEY, 1962), indicating that the order of crystallization of plagioclase and pyroxene is reversed at slightly elevated water pressure. And amphibole appears earlier than pyroxene about 5,300 bars. Amphibole + olivine + clinopyroxene + magnetite were found in equilibrium over a finite range at 5,000 and 10,000 bars water pressure.

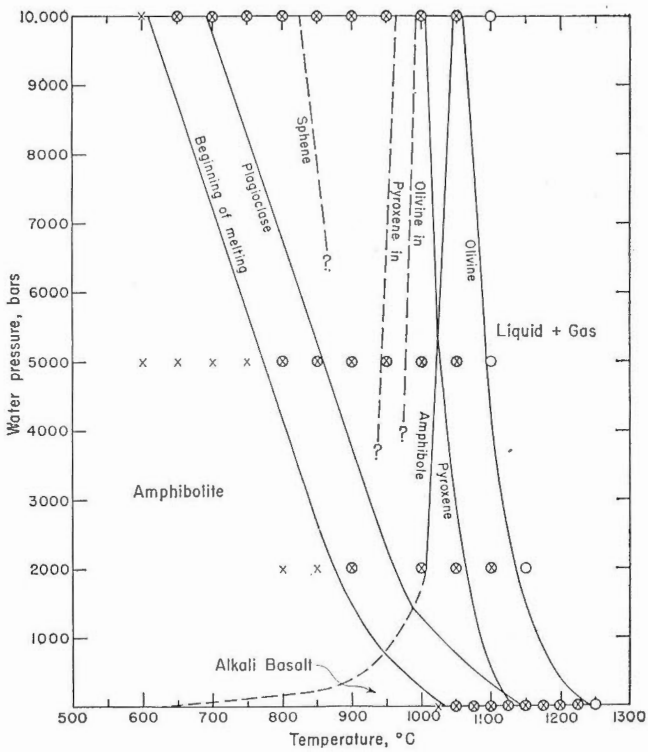


Figure 16. Projection of the natural alkali basalt-water system using data on prehistoric flow from Hualalai, north of Keauhor, Hawaii (melting relation in an alkali basalt, after YODER and TILLEY, 1962, P. 452).

NAKAMURA who studied hypotical equilibrium relation with respect to crystallization of calciferous amphiboles from the Toba ultrabasic complex also thought that the two distinct courses of crystallization under high water pressures, namely, olivine → clinopyroxene + amphibole and olivine → amphibole, may be reflected in the difference of the compositional ranges of hornblendes from clinopyroxene-hornblende rocks and olivine-hornblende rocks, and the composition of hornblende is controlled by the composition of the host rocks. HERMES (1968 and 1970) also has thought that hydrous silicates, containing hornblende, from the Macklenburg gabbro～metagabbro complex, North Carolina, were formed under the conditions that the fugacity of H_2O was relatively high during primary crystallization.

Hornblendes themselves from the Yakuno Basic Rocks are essentially considered to have been crystallized under the condition of high water vapor pressure as described by YODER and TILLEY, NAKAMURA, HERMES and others, mentioned above, during crystallization differentiation of incipient magma probably of alkalic basalt series, according to the Kuno's diagram illustrated in Figure 9. The various rock facies of hornblende-bearing gabbroic rocks, even in small scopes, clinopyroxene-bearing hornblendite—fine-grained hornblende gabbro—medium- and coarse-grained hornblende gabbro—pegmatitic gabbro, any of which does not contain olivines even as relicts, might have been respectively formed under somewhat different conditions of water content or pressure with slight gradual changes of magma's composition during its crystallization, probably according to the above-mentioned two courses by NAKAMURA (1971). Compositional variations of the amphiboles excluding the xenolitic fine-grained ones shown in the preceding chapter are presumable to have been reflected by the slight change of chemical compositions of host rocks (see, Figure 15).

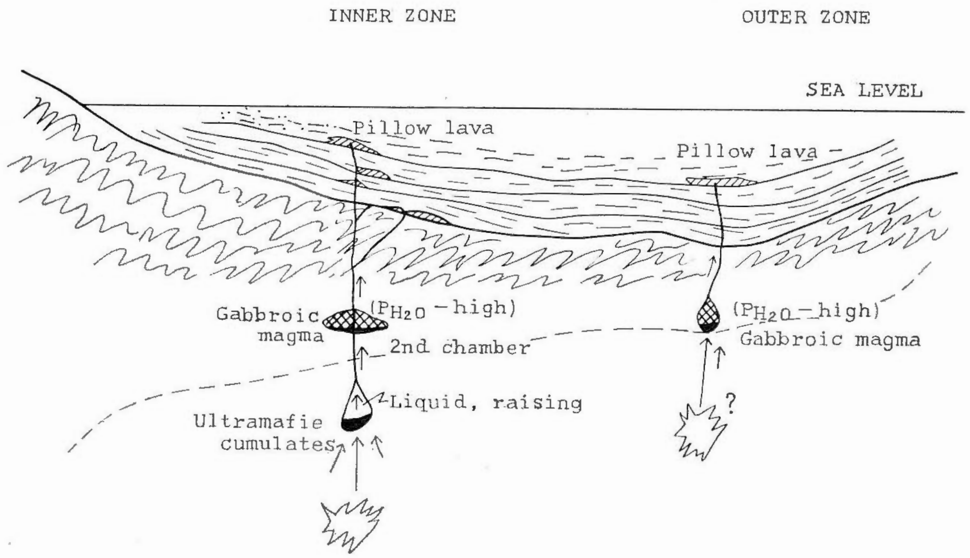
VIII. 2 Genetic relations of the Yakuno Complex

The gabbroic rocks composed mostly of hornblende and plagioclase are found not only from the metamorphic terranes of high pressure type but of high temperature type in Japan ; also in foreign countries, those from the Baltimore (COHEN, 1937 ; HERZ, 1951), Macklenburg, North Carolina (HERMES, 1968 and 1969) ; Union Bay, Alaska (TAYLOR and NOBLE, 1960) and others, are well-known. The gabbroic equivalents with ultramafic intrusions and basic volcanic rocks are also commonly found in the eugeosynclinal regions in the world, even in Japan (BENSON, 1926 ; AUBOUIN, 1965 ; MIYASHIRO, 1966 ; KURODA and TAZAKI, 1969 ; NAKAMURA, 1971 ; SUZUKI, 1972 ; IWASAKI, 1972 ; and others), although it is rather doubtful whether the combination of these rocks corresponds to "Ophiolites" or "Ophiolite suites" after the STEIMANN's trinity(1906) or not. Such gabbroic rocks, in any case, must played the important roles in the respective orogeneses.

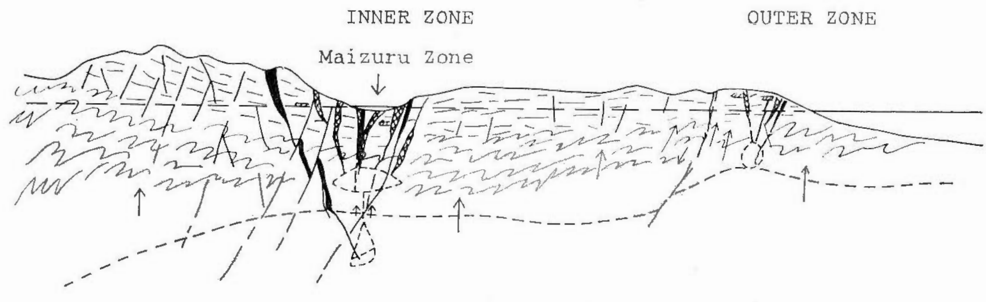
The Yakuno Basic Rocks, as well as those in the other orogenic belts, occupying the great part of the Yakuno Complex, are also considered to have played the most important roles geologically and tectonically on the generation and construction of the Yakuno Complex, concerning one of orogeneses in the Japanese Islands, as seen in the light of the present researches, even until the time that they have been settled in recent positions associated with the Maizuru structural belt. The diversity of the basic rocks, as previously mentioned, might have been also due to the difference of water pressure in part to part at the time of crystallization differentiation in company with fractionation by gravitational setting or cumulation of early formed crystals in the magma chamber under the complicated circumstances with the crustal or structural movements at the depth.

The processes of the differentiation and emplacement of the gabbroic magma associated with the Yakuno Complex are schematically illustrated in Figure 17. In the deep-seated magma chamber generated under the geosynclinal basin at Carboniferous to early Paleozoic times, some crystals such as olivine and pyroxenes, which might be main mineral compositions of ultramafic rock, accumlated at the bottom of the chamber. The liquid rose up to the basement crust of the geosyncline through the fracture related to the depression of geosyncline, and made the second magma chamber, probably corresponding to gabbroic magma (KUNO, 1969). A part of the magma has, then, been erupted in the submarine on the geosynclinal basin as pillow lava, and others, reserved in the crust to form ultramafic, gabbroic and granitic rocks by differentiation and crystallization which took place under higher water pressure at a certain depth shallower than 30 km, judging from the experimental data after YODER and TILLEY (1962), and others (Figure 17-a). Higher water content in the second magma chamber was provided probably not only from the surrounding rock, but primarily from upper mantle (HESS, 1955 ; YODER, 1966 ; KUSHIRO, 1966 and 1968 ; NISHIKAWA, KUSHIRO and UYEDA, 1971).

Then, first, the gabbroic accumulation, occupying the great part of the magma cha-



(a) Carboniferous - Early Permian Times
(Geosyncline Period)



(b) Early Mesozoic Time (Mountain-building Period)

Figure 17. Schematic illustration showing the differentiation and emplacement of igneous rock-types of the Yakuno Complex.

mber, in the state of crystal mush, ascended into the geosynclinal sediments with the fragments of surrounding crystalline basement by the upward movement of mountain-building stage in the late Permian and the early Mesozoic times. Successively, granitic derivatives rose up, and ultramafic cumulates, together with them, on the bottom of the prior magma were also brought up along the fracture zones to the present positions of the Maizuru structural or Sangun metamorphic belts (Figure 17-b).

Gneissose appearance, a kind of plutonic flow structure, which characterized the Yakuno Basic Rocks, is considered to have taken place by partial stress during their intrusion in the state of crystal much.

As shown in Figure 18, the scope of the Yakuno Basic Rocks for chemical compositions and magmatic rocks series (KUNO, 1966) are rather included in those of the

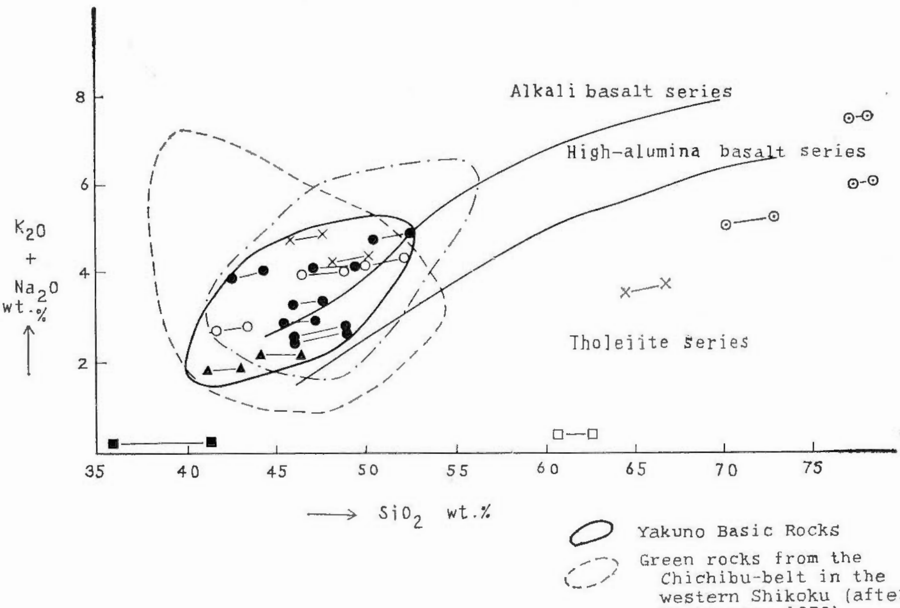


Figure 18. Distribution areas of the plotted points for the paleozoic basic or green rocks from the Chichibu belt in alkali-silica diagram for the "Yakuno Complex", after KUNO, 1966. Symbols correspond to those in Fig.3 (Fig. 8).

Paleozoic geosynclinal basic volcanic rocks. As to the primary magma series of the Japanese Paleozoic basic volcanic rocks, "geosyncline basaltic rocks", the researches based on the chemical compositions of the rocks are recently done by several investigators (TANAKA, 1970 ; HASHIMOTO, et al., 1970 ; KANISAWA, 1971 ; and others). The Yakuno intrusive rocks might also be associated with these volcanism at that time.

If the ultramafic rocks associated to the Yakuno Complex are only of the dunite-wehrlite series as those in the Sambagawa metamorphic belt (RESEARCH GROUP of

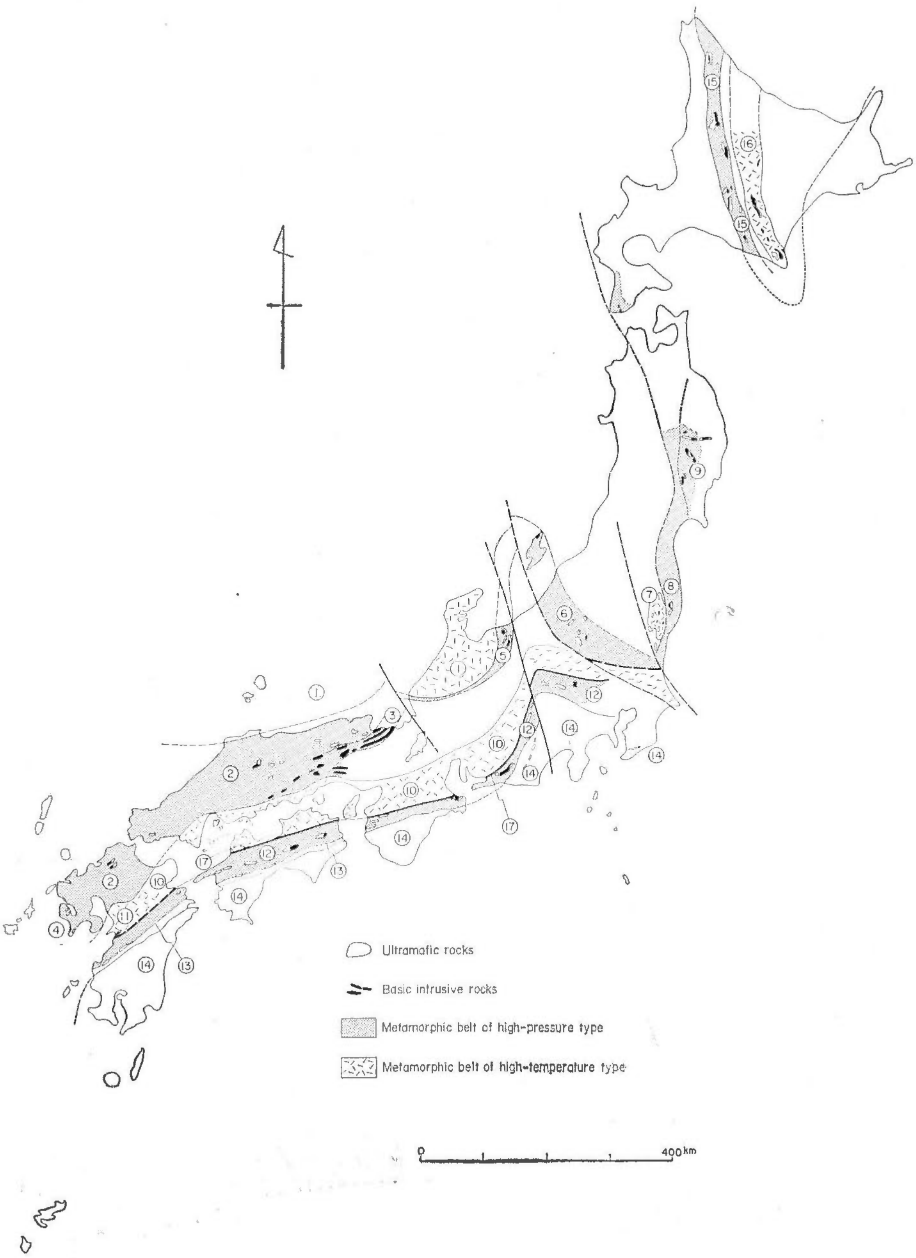


Figure 19. The zonal arrangements of metamorphic and tectonic belts of Japanese Island Arcs with reference to the distribution of the Yakuno Basic Rocks and their affinities.
1. Hida belt 2 Chugoku (Sangun metamorphic) belt 3. Maizuru structural belt
4. Nagasaki metamorphic terrane 5. Hida outer-structural belt 6. Joetsu belt
7. Abukuma mountains 8. Abukuma-outer metamorphic belt 9. Kitakami mountains
10. Ryoke belt 11. Higo metamorphic terrane 12. Sambagawa-Chichibu belt
13. Kurosegawa structural belt 14. Shimanto belt 15. Kamuikotan belt 16. Hidaka belt

PERIDOTITE INTRUSION, 1970), it is reasonable to suppose that the Yakuno Basic Rocks and their associated ultramafic rocks together might be derived from the same magma chamber as those of the Paleozoic volcanic rocks, as well as the Toba ultrabasic complex (NAK-AMURA, 1971).

VIII. 3 Geotectonical situation of the Yakuno Complex in the Japanese Islands

The Japanese Islands are constructed by the several metamorphic or tectonic belts with zonal arrangements, trending towards NNW-SSE direction in Northeast Japan, and ENE-WSW, in Southwest Japan, roughly parallel to the trends of Japanese Island Arcs, as shown in Figure 19, which is based on a figure by KURODA, IGI and KANO (1972). The Yakuno Complex is included principally in the Maizuru structural belt between the Chugoku (Sangun metamorphic) and Tamba belts in Southwest Japan. The analogical gabbroic rocks to the Yakuno Basic Rocks are found often in the various metamorphic belts, especially of the high pressure type, as denoted also in Figure 19. Most of them are merely called "metagabbro". The resemblances, in chemical composition, in geology and even in alteration, of these gabbroic rocks may be due to their formations under the same geological circumstances. As given in Table 8, the metamorphic terranes of high pressure type in Japan are characterized by coexistence of glaucophane-bearing schists (blue schist), metagabbros and ultramafic rocks. The author would like to propose that the combination of these rocks associated genetically and geotectonically with each other should be called as "Rock-trio" of the metamorphic terranes, not after the STEINMANN's trinity.

A crustal profile of the Kinki district, Southwest Japan, compiled by ICHIKAWA and KOJIMA (1964) after the results of researches by the members of "C-zone" group, the structural geology discipline of the Japanese Upper Mantle Projects (Figure 20), gives also the present geological position of the Yakuno Complex, illustrated as granitic-gabbroic complex in it. The Maizuru metamorphic rocks are considered to be the fragments of the Precambrian crystalline basements of the "lower part of crust" by them and correlatively to be the same as those of the Kurosegawa structural and Hida metamorphic belts (ICHIKAWA et al., 1956). These rocks have not yet enough been given the proofs by means of the isotopic age-determinations, although the results by YAMAGUCHI (1967) and SATO et al. (1967) are well known (1,493 m.y. for zircon from gneiss and 1,200 m.y. for whole rock of granite, respectively), and also age of some metamorphic gravels from the Kamiaso conglomerate, Gifu Prefecture, have recently been estimated to be about 1,300—1,700 m.y. by SHIBATA and ADACHI (1972). The ages of the biotite from the biotite gneiss of the Maizuru metamorphic rocks were about 210 m.y. (SHIBATA and IGI, 1966).

Besides, the ages of the Yakuno Basic Rocks have not yet been known, excepting some unpublished data from hornblende.

The geotectonical differences between the igneous rocks in the Inner and Outer Zones of Southwest Japan, related with the Paleozoic geosyncline and its successive mountain-building movement, are also schematically and roughly illustrated in Figure 17.

In the Inner Zone, plutonic rocks at the mountain-building stage after geosynclinal stage of the Orogenic cycle, were brought up to the present positions through two steps ; that is, there were two magma chambers, deep-seated chamber and second chamber up-raised into the crust. Ultramafic rocks of dunite-harzburgite series occurring as rather large masses, were derived from the deep one ; while, those of dunite-wehrlite

Table 8. Some characteristic features of the metamorphic belts of the high pressure type, including blue schist, Japan.

Metamorphic belt	Metamorphic grade	Relation between principal ultramafic and gabbroic rocks
Kamuikotan——	(P.P.) ⟶ G.⟶ E.A.	Serpentinite (Dunite-harzburgite) ➡ Meta-hornblende gabbro
Motai (Kitakami) ——	G.	Serpentinite : Metagabbro
Yaguki——	⟶ G.	Serpentinite : Metagabbro
Jōetsu ——	G.⟶E.A.	Serpentinite : Metagabbro
Sangun——	⟶ G.⟶E.A. (?)	
including Maizuru——		Serpentinite (Dunite-harzburgite-others) ➡ Metagabbro
Nagasaki——	G.⟶	Serpentinite : Metagabbro
Sambagawa——	(P.P.) ⟶G.⟶ (A.)	Serpentinite (Dunite-wehrlite) ➡ or=Metagabbro

P.P. : Prehnite-pumpellyite facies

G. : Green schist (glaucophanitic～blue schist) facies

E.A. : Epidote amphibolite facies

A. : Amphibolite facies

➡ : Intruding

= : Including

: : Separated from each other

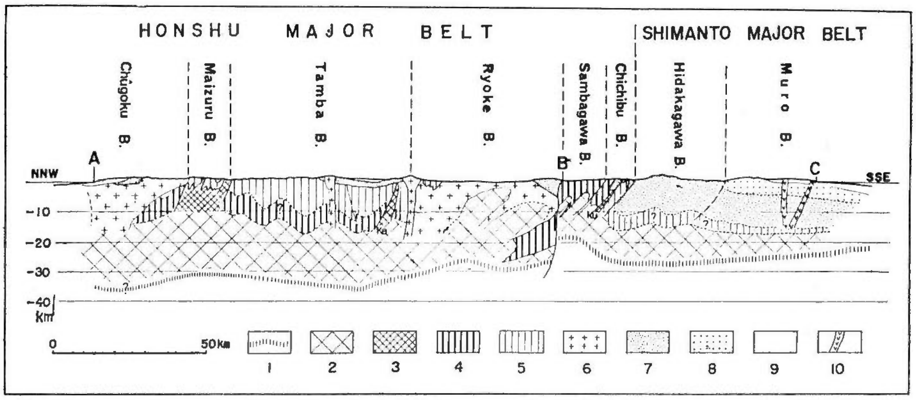


Figure 20. Crustal profile of the Kinki district, Southwest Japan, compiled by Ichikawa and Kojima (1964).

1. Moho-discontinuity ; 2. "Lower part" of the crust ; 3. Older granitic-gabbroic complex and presumed Pre-Cambrian in tectonic zones of the "upper part" of the crust ; 4~10. "Upper part" of the crust ; 4. Crystalline schists derived from Paleozoic rocks ; 5. Paleozoic ; 6. Granitic complex, mainly Mesozoic ; 7. Mesozoic ; 8. Paleogene ; 9. Neogene ; 10. Neogene acidic rocks.

series, occurring as small masses, probably from the second one. On the other hand, in the Outer Zone, plutonic rocks, containing ultramafic rocks of dunite-wehrlite series, were brought up only from the shallower magma chamber like as secondary one in the Inner Zone, and they occur merely as small masses. It is presumable that in the Outer Zone, ultramafic rocks were not derived from the deep-seated magma chamber as guessed in the Inner Zone, but only from the gabbroic magma chamber settled at the shallower parts of the upper mantle or crust.

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(JwE) : (in Japanese with English abstract)
(J) : (in Japanese)

西南日本内帯の"夜久野複合岩体"中の変はんれい岩とその関連岩類

猪 木 幸 男

要 旨

西南日本内帯の舞鶴構造帯に発達する"夜久野複合岩体"には，変はんれい岩類，花崗岩類および変成岩類のほかに，超塩基性岩類が伴われており，それぞれの岩石はいずれも岩相変化がはげしい．このなかで最も多いものは"夜久野塩基性岩"とよばれている変はんれい岩類である．このような夜久野複合岩体には，大きくみて次のような岩石種が区別される．

夜久野塩基性岩
　細粒角閃石はんれい岩
　中粒ないし粗粒角閃石はんれい岩
　ペグマタイト質角閃石はんれい岩
　輝石含有角閃石はんれい岩
　角閃石岩
舞鶴花崗岩
　アダメロ岩
　トーナル岩ないし石英閃緑岩
　トロニエム岩
　文象岩
　"珪長岩"
舞鶴変成岩
　黒雲母片麻岩ないし片岩
　角閃岩
付随超塩基性岩類
　蛇紋岩
　かんらん岩
　輝岩

酸性および塩基性の迸入岩類の間には，次のような迸入あるいは形成順序が推定される．つまり，角閃石岩-？-輝石含有角閃石はんれい岩―細粒角閃石はんれい岩→中粒ないし粗粒角閃石はんれい岩→ペグマタイト質角閃石はんれい岩→花崗岩類である．また，それぞれの岩石種の代表的試料に対する化学分析の結果を，久野（1966）のアルカリ―シリカ関係図にプロットしてみると，夜久野塩基性岩類は，アルカリ玄武岩系列および高アルミナ玄武岩系列の領域におち，舞鶴花崗岩類はソレイアイト系列の領域におち，変化に富んでいる．

夜久野塩基性岩中の角閃石も，YODER and TILLEY（1962），HERMES（1968および1970），NAKAMURA（1971）その他によって述べられているものと同様に，高い水蒸気圧の条件の下に形成されたと考えられるが，それらの中の Al^{IV} と Na の原子比に特徴がみられる．すなわち，角閃石岩―細粒角閃石はんれい岩―中ないし粗粒角閃石はんれい岩―ペグマタイト質はんれい岩といった前述の形成順序に従って，それぞれの原子比が減少してゆく傾向のみられることである．

舞鶴帯の超塩基性岩類は，他の変成帯のものと違い（RESEARCH GROUP of PERIDOTITE INTRUSIONS,

1967)，dunite-harzburgite series の岩石と dunite-wehrlite series の岩石が混ざっている．

以上のような事実から，次のような夜久野複合岩体の形成が考察されるのではなかろうか．すなわち，石炭紀および二畳紀前半におこった地向斜の堆積盆地の地下深部において発生した岩しょうは，その一部が dunite-harzburgite series の苦鉄質鉱物を cumulate した後，比較的浅所に上昇してはんれい岩質岩しょうとなり，そこで岩しょう分化が行なわれ，dunite-wehrlite series の超塩基性岩，夜久野塩基性岩，舞鶴花崗岩が生じた．その後，引続き，二畳紀末から三畳紀にかけての造山運動によって生じた剪断帯に沿って，付近の変成岩類とともに，舞鶴帯の現位置に，これらの岩石はもたらされた．その時，深部の dunite-harzburgite series の超塩基性岩も同様にして上昇し，主として三郡変成帯中にもちこまれ，その一部は舞鶴帯にももたらされた．

地　名

Aonogo ······························ 青　郷
Arakura ····························· 荒　倉
Asako ······························· 朝　来
Ayabe ······························· 綾　部
Fukotoge ···························· 不甲峠
Fukuchiyama ························· 福知山
Kumita ······························ 久美田
Hijima ······························ 土　万
Hoshihara ··························· 星　原
Ikemon ······························ 池　門
Kamigori ···························· 上　郡
Kishitani ··························· 岸　谷
Komori ······························ 河　守
Maizuru ····························· 舞　鶴
Makabe ······························ 真　壁
Miharaiyama ························· 御祓山
Mutsushi ···························· 睦　市
Nabae ······························· 難波江
Ōeyama ······························ 大江山
Ohara ······························· 大　原
Okada ······························· 岡　田
Oya ································· 大　屋
Oyogi ······························· 於与岐
Seki ································ 関
Shidaka ····························· 志　高
Sugesaka ···························· 菅　坂
Takakura ···························· 高　倉
Umezaka ····························· 梅　迫
Yakuno ······························ 夜久野

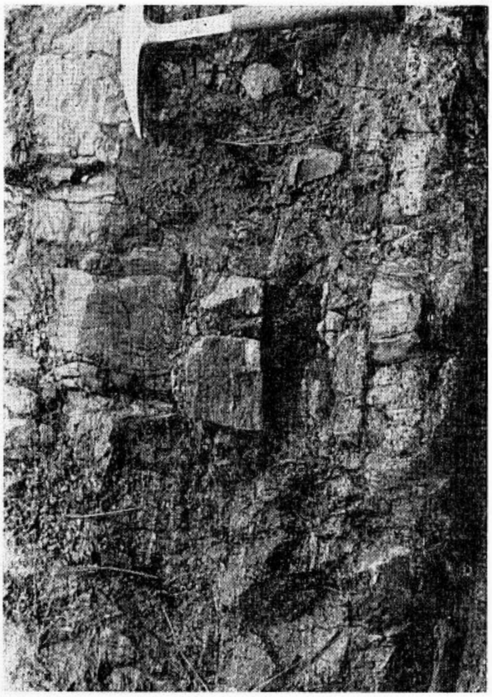
PLATES
AND
EXPLANATIONS

(With 4 Plates)

Plate I

1. Rhythmic banded layers of the basic and acid intrusive rocks of the Yakuno Complex in a road cut (Ōhara-cho, Okayama Prefecture).
2. Gneissose structure of the Yakuno Basic Rock seen in the same road cut as in *Plate* I-1 (Ōhara-cho, Okayama Prefecture).
3. Gneissose structure of the Yakuno Basic Rock in a outcrop (Ōya-cho, Hyogo Prefecture).
4. Pegmatitic gabbro occurring as vein rock in the medium grained metagabbro (Oyogi, Ayabe City).

1



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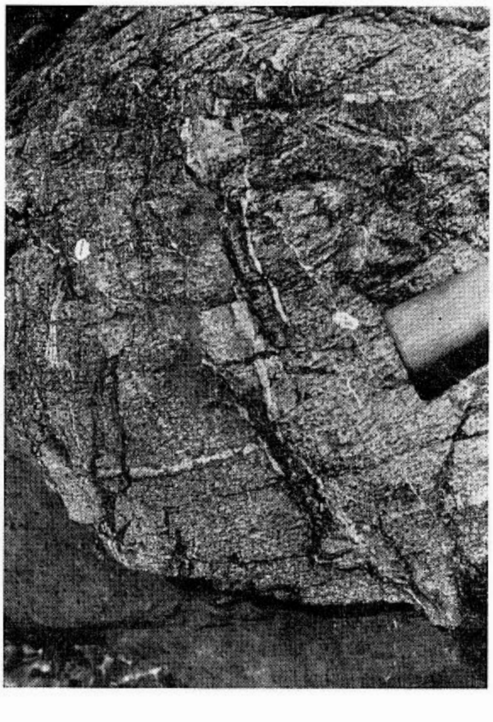

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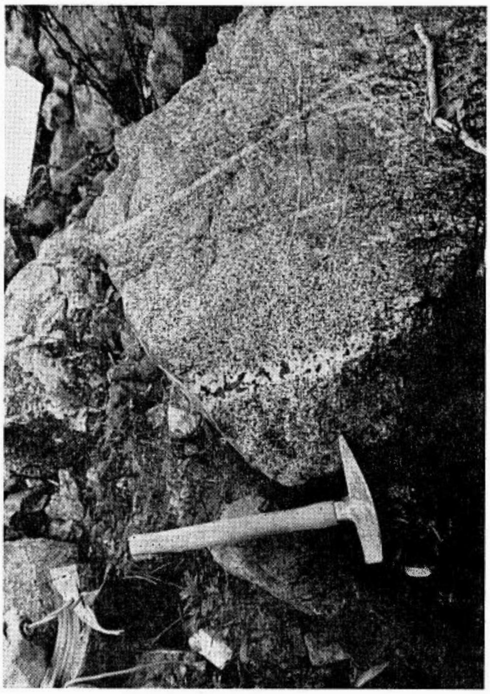


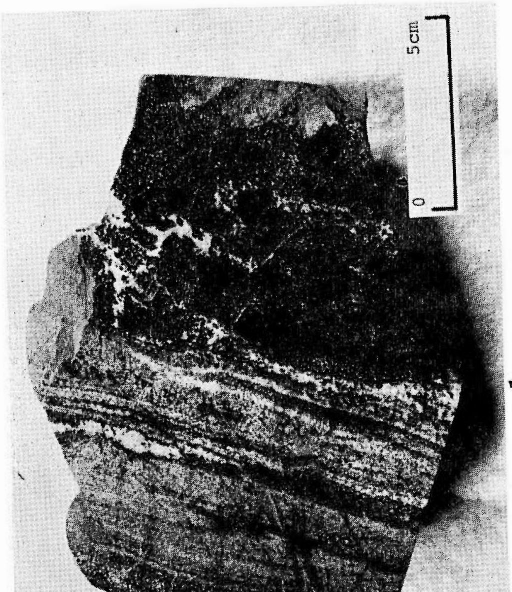
4

Plate II

1. A rock-specimen of medium-grained metagabbro bearing layered various rock facies from Yohoro, Maizuru City (M-224).
2. A rock-specimen of medium-grained metagabbro including fine-grained variety (metamorphic amphibolite ?), from Kishitani, Maizuru City (Y62-33).
3. A rock-specimen of biotite amphibolite included into the medium-grained metagabbro, from Asako-cho, Hyogo Prefecture (Y62-136).
4. A rock-specimen of garnet biotite gneiss (Maizuru or Komori Metamorphic Rock) , from Ōe-cho, Kyoto Prefecture (O-309).

2

4



1

3

Plate III

1. Photomicrograph of fine-grained hornblende gabbro (injected by coarse-grained metagabbro). One polaroid.

    H : Green hornblende
    P : Altered plagioclase
    PH : Prehnite vein

    Locality : Oyogi, Ayabe City (M-251).

2. Photomicrograph of hornblendite. One polaroid.

    H : Brown hornblende

    Locality : Umezako, Ayabe City (M-237).

3. Photomicrograph of medium- or coarse-grained metagabbro. One polaroid.

    H : Greenish brown hornblende
    P : "Saussuritized" plagioclase

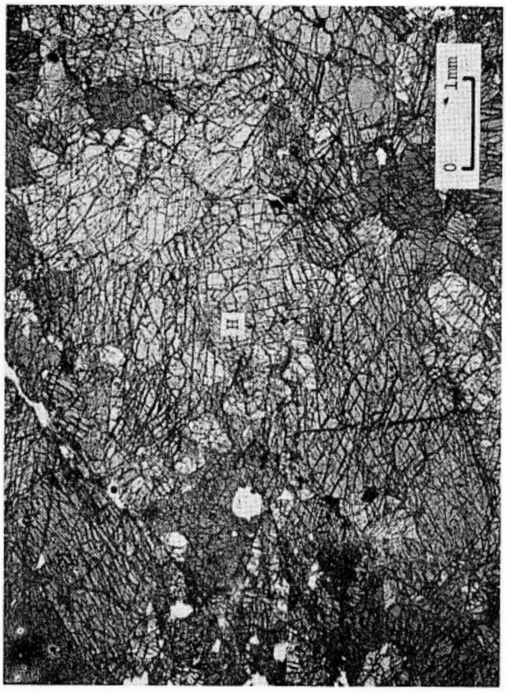
    Locality : Mutsushi, Ayabe City (M-286).

4. Photomicrograph of clinopyroxene-bearing hornblende gabbro. One polaroid.

    H : Brown hornblende
    CP : Clinopyroxene
    P : "Saussuritized" Plagioclase

    Locality : Aonogo, Fukui Prefecture (M-87).

1



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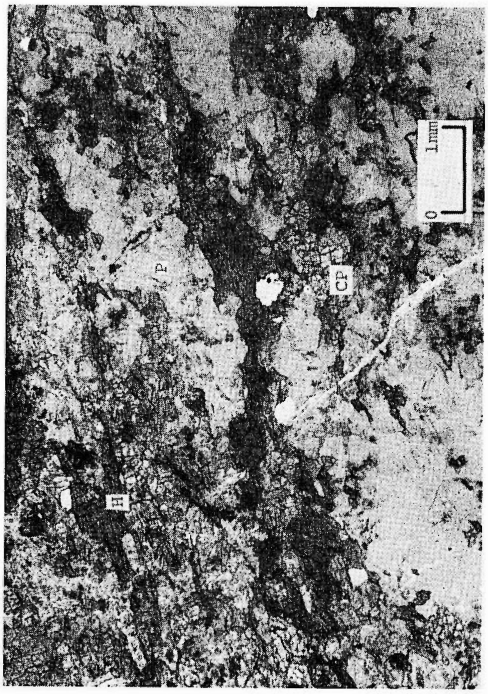


4

Plate IV

1. Photomicrograph of protoclastic quartz diorite (sheet-formed) in the Yakuno Basic Rock (Maizuru granites). Crossed two polaroids.

   P : Plagioclase
   Q : Quartz
   B : Altered biotite

   Locality : Sugesaka, Ayabe City (M-24).

2. Photomicrograph of protoclastic and cataclastic fine-grained granite (Maizuru granites). Crossed two polaroids.

   P : Plagioclase
   Q : Quartz
   Kf : Potassium feldspar
   B : Altered biotite

   Locality : Wada, Maizuru City (M-203).

3. Photomicrograph of biotite amphibolite (Maizuru or Komori Metamorphic Rocks). One polaroid.

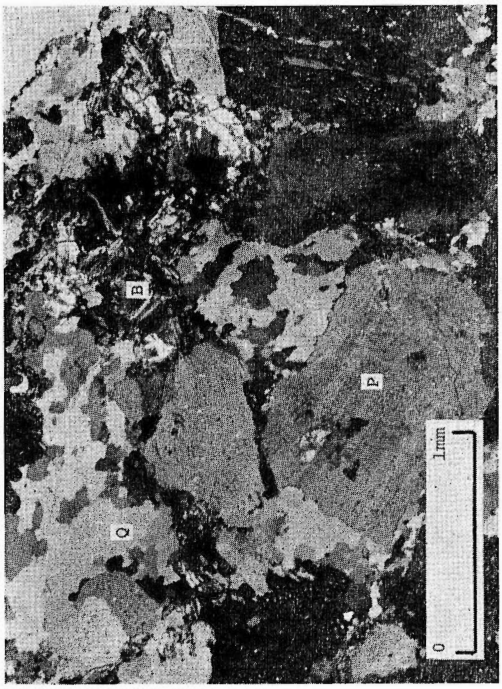
   P : Plagioclase
   H : Green hornblende
   B : Biotite
   Q : Quartz

   Locality : Sugesaka, Ayabe City (M-1-60).

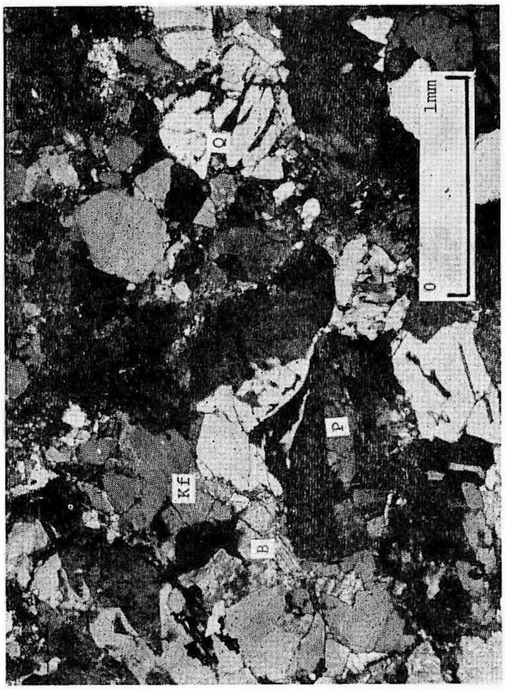
4. Photomicrograph of amphibolite (Maizuru or Komori Metamorphic Rocks). Crossed two polaroids.

   P : Plagioclase
   H : Green hornblende

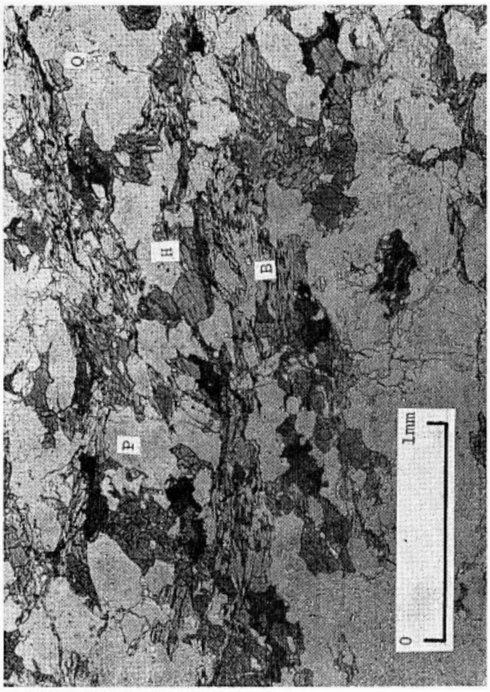
   Locality : Sugesaka, Ayabe City (M-4-60).



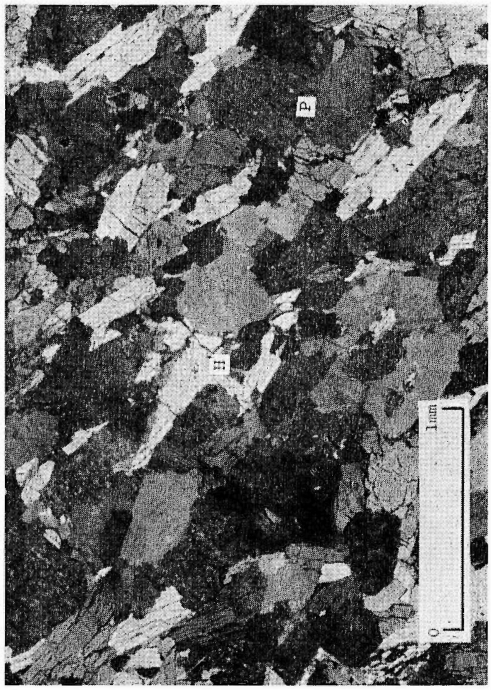
1



2



3



4

地質調査所報告は１報文について報告１冊を原則とし，その分類の便宜のために，次のようにアルファベットによる略号をつける．

A．地質およびその基礎科学に関するもの
- a．地　質
- b．岩石・鉱物
- c．古生物
- d．火山・温泉
- e．地球物理
- f．地球化学

B．応用地質に関するもの
- a．鉱　床
- b．石　炭
- c．石油・天然ガス
- d．地下水
- e．農林地質・土木地質
- f．物理探鉱・化学探鉱および試錐

C．そ の 他

D．事業報告

As a general rule, each issue of the Report, Geological Survey of Japan will have one number, and for convenience's sake, the following classification according to the field of interest will be indicated on each Report.

A. Geological & allied sciences
- a. Geology
- b. Petrology and Mineralogy
- c. Paleontology
- d. Volcanology and Hot spring
- e. Geophysics
- f. Geochemistry

B. Applied geology
- a. Ore deposits
- b. Coal
- c. Petroleum and Natural gas
- d. Underground water
- e. Agricultural geology and Engineering geology
- f. Physical prospecting, Chemical prospecting & Boring

C. Miscellaneous

D. Annual Report of Progress

地質調査所報告

第 243 号

KAWADA, K. : Geology and petrology of the Nōhi rhyolites, with special reference to those along the Hida river, 1971

第 244 号

HOSHINO, K., KOIDE, H., INAMI, K., IWAMURA, S. and MITSUI, S. : Mechanical properties of Japanese Tertiary sedimentary rocks under high confining pressures, 1972

第 245 号

井上英二：北西九州，唐津炭田の古第三系杵島層の岩相変化と化石群集からみた堆積環境，1972

第 246 号

片田正人・松井和典：北西九州，相の島帯の変成岩類，1973

第 247 号

小川克郎：空中磁気図解析・解釈法の研究，1973

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No. 243

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No. 245

INOUE, E. : Lithofacies, fossil assemblages and sedimentary environment of Oligocene Kishima Formation in Karatsu coalfield, northwest Kyushu, Southwest Japan, 1972 (in Japanese with English abstract)

No. 246

KATADA, M. and MATSUI, K. : Metamorphic rocks of the Ainoshima belt in northwestern Kyushu, Japan, 1973 (in Japanese with English abstract)

No. 247

OGAWA, K. : A study of the method for interpretation of aeromagnetic maps, 1973 (in Japanese with English abstract)

Igi, S.

The Metagabbros and Related Rocks of the "Yakuno Complex" in the Inner Zone of Southwest Japan

Sachio Igi

Report, Geological Survey of Japan, no. 248, p. 1～42, 1973
20 illus., 4 pl., 8 tab.

The "Yakuno Complex" in the Maizuru Structural Belt, Southwest Japan, contains the various kinds of rocks, such as metagabbroic and granitic rocks, associated ultramafic rocks, and even higher-grade metamorphic rocks. Of these rocks, metagabbro, called as "Yakuno Basic Rock", is extremely conspicuous among them. The characteristic features of metagabbros are petrographically and petrochemically described in this paper, with mineralogy of amphiboles from them. The genetic retation between gabbroic rocks and related rock are also discussed.

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