PLUTONIC AND METAMORPHIC ROCKS OF MASSIF-A IN THE YAMATO MOUNTAINS, EAST ANTARCTICA

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Abstract: Geological and petrographical observations of crystalline basement rocks occurring in Massif-A of the Yamato Mountains are briefly described as a report of the geological works of the 21st Japanese Antarctic Research Expedition in 1979–1981.

The basement rocks are composed of various kinds of acid to intermediate plutonic rocks and subordinate amounts of acid, basic and calcareous metamorphic rocks. The metamorphic rocks such as banded two-pyroxene biotite gneiss, two-pyroxene metabasites and calc-silicate gneiss, and the plutonic rock such as massive quartz syenitic rock make up the oldest rocks, followed by intrusions of the quartz syenitic charnockites and the subsequent quartz monzonite. The latest plutonism and related metamorphism are represented by intrusion of the granitic migmatite, with biotite gneiss and amphibolite paleosomes, into the quartz monzonite, and by development of the migmatitic biotite gneiss with granitic neosomes, though their occurrence is local.

The rocks composing Massif-A could be grouped into two stages of plutonic and metamorphic rock association mainly on the basis of their modes of occurrence; the older association includes the rocks from the oldest ones to the quartz monzonite, and the younger association all the migmatitic rocks. Mineral assemblages of the metamorphic rocks enclosed in the plutonic rocks of the both associations suggest that the older plutono-metamorphic activity would have taken place under the granulite facies condition, while the younger activity under the amphibolite facies condition.

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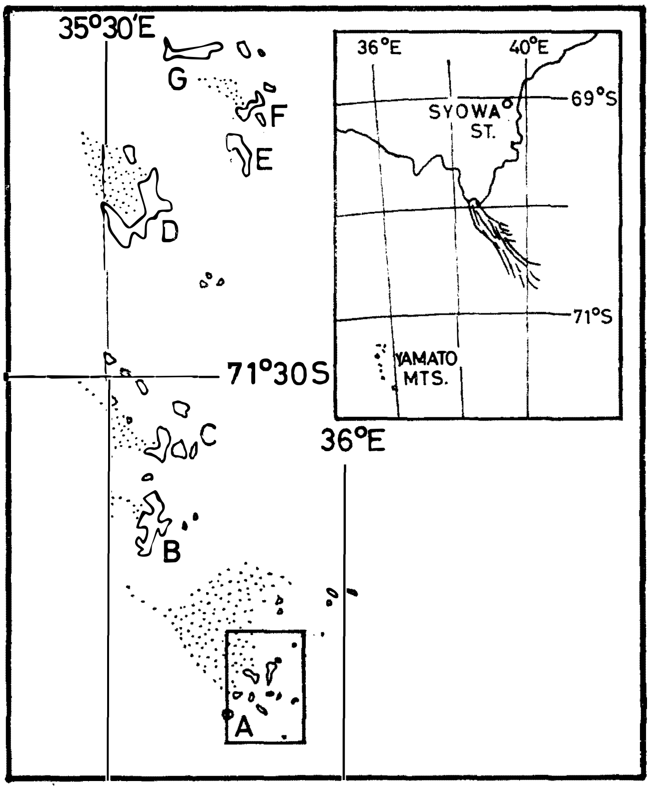

Fig. 1. Location map of the Yamato Mountains.

1. Introduction

The Yamato Mountains is situated about 300 km southwest of Syowa Station on Ongul Island, and is composed of seven groups of nunataks, provisionally named Massif-A to -G from the south to the north (Fig. 1). Since the 4th Japanese Antarctic Research Expedition (JARE-4, 1959–1960), geological survey had been carried out in different parts of the Mountains by the parties of the JARE-10, -14, -15, -16 and -20, and some of the results were already published (KIZAKI, 1965; OHTA and KIZAKI, 1966; YOSHIDA and ANDO, 1971; SHIRAISHI, 1977). In order to compile the geology of the whole Mountains, we, the members of the JARE-21, carried out further field survey of the six massifs, except for Massif-C, from January 3 to February 3, 1980, and one of us, K. SHIRAISHI, made an additional field work from December 6 to 16, 1980.

This paper presents a geological outline and brief petrography of the plutonic and metamorphic rocks of Massif-A.

2. Geological Setting and the Rock Types

Maffis-A, being located at 71°43′S in latitude and 35°51′E in longitude, oc-

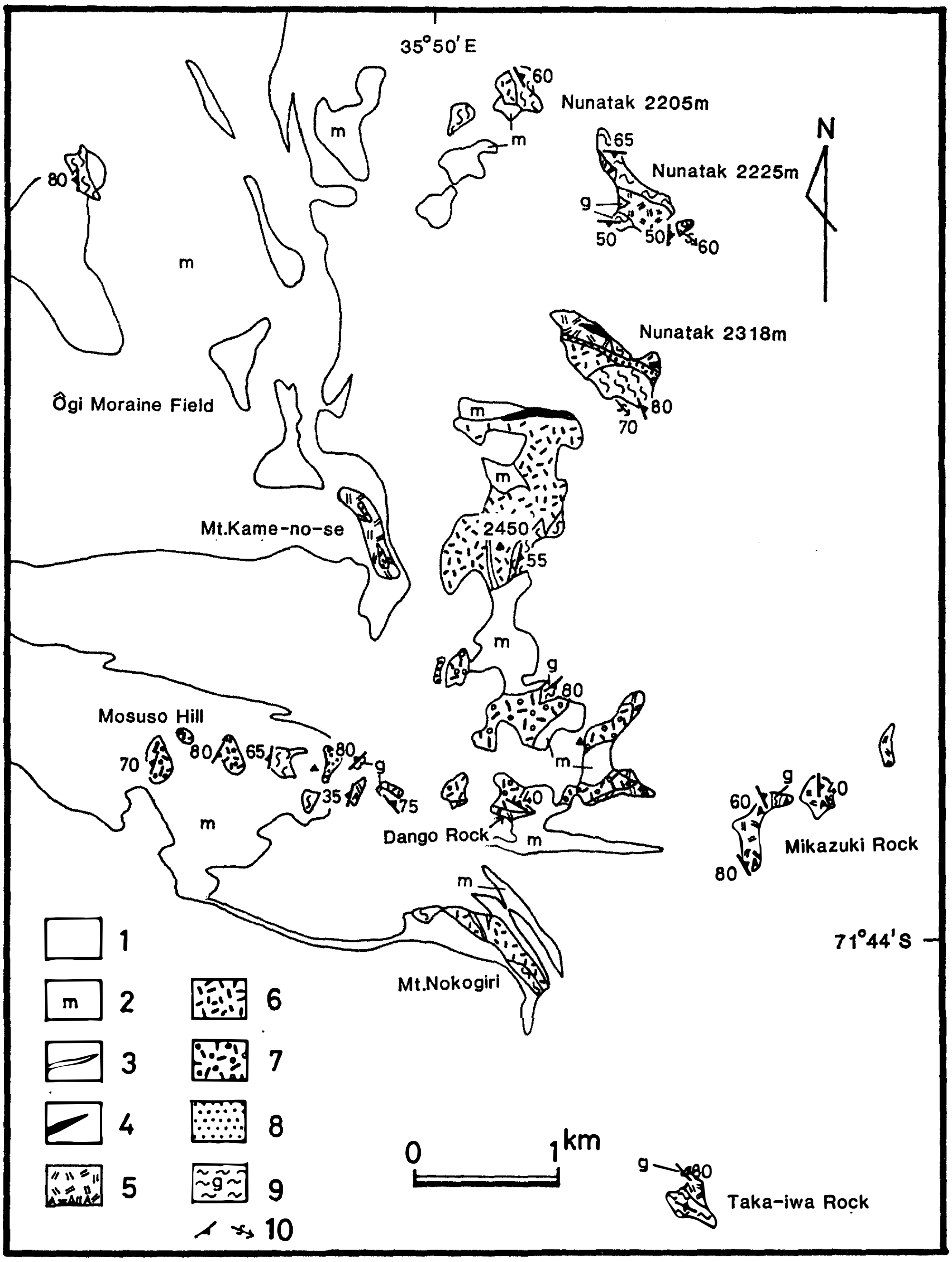

Fig. 2. Geologic map of the Massif-A and surroundings. 1. Snow and ice. 2. Morainic debris. 3. Granites and pegmatite. 4. Granitic migmatite. 5. Quartz monzonite, "A" shows agmatitic blocks. 6. Fine-grained massive quartz syenitic charnockite. 7. K-feldspar-porphyroblastic quartz syentitic charnockite. 8. Massive quartz syenitic rock. 9. Metamorphic rocks. 10. Foliation and folding axis.

cupies the southernmost part of the Yamato Mountains, and consists of the main massif, the highest point of which is 2450 m above sea level, and of several nunataks surrounding the main massif. Outcrops are scarce, since most of the ice-free area is widely covered with the morainic debris.

The Yamato Mountains is composed of various kinds of metamorphic and plutonic rocks. KIZAKI (1965) classified them into two major groups: the older charnockitic group and the younger granitic group. Massif-A is composed of the rocks of the charnockitic group. The geological map of the area is shown in Fig. 2.

The constituent rocks of Massif-A can be classified into the following rock types based on the mode of occurrence, lithologic facies and mineral assemblages.

A. Metamorphic rocks
 1) Banded two-pyroxene biotite gneiss
 2) Migmatitic biotite gneiss
 3) Calc-silicate gneiss
 4) Metabasites
  a) Two-pyroxene gneiss
  b) Two-pyroxene amphibolite
  c) Amphibolite

B. Plutonic rocks
 1) Massive quartz syenitic rock
 2) Quartz syenitic charnockites
  a) K-feldspar-porphyroblastic charnockite
  b) Fine-grained massive charnockite
 3) Quartz monzonite
 4) Granitic migmatite

C. Dike rocks
 1) Metamorphosed basic dike rocks
 4) Granites, pegmatite and aplites

3. Metamorphic Rocks

The largest mass of the metamorphic rocks is found at Nunatak 2318 m. The other small masses are on the eastern side of the central part of the main massif, near the eastern peak of the Mosuso Hill and so on (Fig. 2).

Banded two-pyroxene biotite gneiss, showing a distinct banded structure represented by an alternation of mafic-rich and felsic-rich layers of a few to 10 mm in thickness, is the most abundant metamorphic rock in the present area. The gneiss consists of orthopyroxene, clinopyroxene, biotite, plagioclase, quartz and a small amount of K-feldspar. Brownish green hornblende rarely occurs. Accessory minerals are apatite, zircon and opaque minerals. Two-pyroxene gneiss of metabasites, a few to 10 cm in width, and charnockitic aplite bands, 10 to 100 cm in width, are concordantly associated with the banded two-pyroxene biotite gneiss. Two-pyroxene amphibolite is found as xenolithic blocks in the charnockitic aplite. The two-pyroxene gneiss is composed mainly of orthopyroxene, clinopyroxene, biotite and plagioclase with or without small amounts of quartz and hornblende. The two-pyroxene amphibolite consists of brown hornblende, orthopyroxene, clinopyroxene, biotite and plagioclase. Accessory apatite and ore minerals occur in all metabasites. Calc-silicate gneiss, a few meters in width, is found as concordant layers in the banded two-pyroxene biotite gneiss on the eastern side of the main massif. This rock is composed of wollastonite, clinopyroxene, scapolite and accessory sphene. Quartz, plagioclase, calcite and green hornblende are sometimes associated with the above mineral assemblage.

The migmatitic biotite gneiss occurs mainly at Nunataks 2225 m and 2205 m in the northernmost part of the area and shows nebulitic and diktyonitic structures, but the banded structure is not distinct. Lit-par-lit injection of pink granite is also found in these localities. At a nunatak in the Ôgi Moraine Field, the two-pyroxene biotite gneiss is converted into the migmatitic biotite gneiss at the contact with a granitic pegmatite. The constituent minerals of the migmatitic biotite gneiss are mainly biotite, K-feldspar (microcline), plagioclase and quartz with accessory apatite and ore mineral. Clinopyroxene and green hornblende are sometimes found. Garnet is found at a locality in Nunatak 2225 m. Amphibolite is sometimes found as concordant layers in the migmatitic biotite gneiss at Nunataks 2225 m and 2205 m. This rock is composed of green hornblende, biotite and plagioclase with or without quartz and clinopyroxene. Accessory apatite and ore minerals are common.

There are many agmatitic blocks, ribbons and lenses of the banded two-pyroxene biotite gneiss and the two-pyroxene gneiss, tens of centimeters long, in the K-feldspar-porphyroblastic charnockite and the quartz monzonite at Dango Rock (local name), Mikazuki Rock, Mosuso Hill and Taka-iwa Rock. These blocks occur in roughly aligned zones in the neosome. Calc-silicate gneiss is also found as larger xenolithic blocks and layers at Mikazuki Rock and Dango Rock. The mineral assemblages of these rocks are almost the same as those mentioned above. Green spinel-biotite-plagioclase gneiss is found as lenses in the quartz monzonite at Mikazuki Rock.

The foliations of the gneisses show a general strike of N-S with steep dips to the east and west. The banded two-pyroxene gneiss often shows small-scale folds whose axes generally plunge 50–60°SE.

4. Plutonic Rocks

4.1. Massive quartz syenitic rock

This rock is found at Nunatak 2318 m and sporadically occurs at Dango Rock, east peak of the Mosuso Hill, and in the western outcrops of the main massif.

The geological relationships to the other rock types are not known because of the lack of the exposures except for an outcrop, 500 m east of the Mosuso Hill. Since lenses of this rock are included just as xenoliths in the K-feldspar-porphyroblastic charnockite at this locality, we refer it to the oldest plutonic rock in the present area.

This rock is characterized by coarse-grained K-feldspar aggregates which are spotted in the clinopyroxene-biotite matrix. Idiomorphic clinopyroxene and biotite laths are scattered inside the K-feldspar grains and its aggregates. Orthopyroxene is found in one specimen. Small amounts of quartz, plagioclase and sphene are also found.

4.2. *Quartz syenitic charnockites*

The rocks of this type occur widely in the main massif and surrounding nunataks, *i.e.* Mosuso Hill, Nunatak 2813 m etc. Though there are some lithologic varieties in this rock type, they could be divided into K-feldspar-porphyroblastic charnockite and fine-grained massive charnockite in general. All varieties are characterized by the presence of blue-gray to brown-gray feldspars. The fine-grained massive charnockite seems to be younger than the K-feldspar porphyroblastic charnockite from the observation at an outcrop, 500 m east of the Mosuso Hill, where the K-feldspar-porphyroblastic charnockite is clearly cut by the fine- to medium-grained massive charnockite.

The K-feldspar-porphyroblastic charnockite typically occurs around the mountain top of the southern part of the main massif. This rock obliquely cuts the banded two-pyroxene biotite gneiss and occasionally includes xenoliths of the gneiss and the two-pyroxene gneiss of metabasites near the contact. K-feldspar porphyroblasts of up to 1 cm in size show distinct schillerization. The charnockite is composed of orthopyroxene, clinopyroxene, biotite, K-feldspar and small amounts of quartz and plagioclase. Some varieties contain brownish green hornblende. Apatite, zircon and ore mineral are contained as accessories. This rock has a weak foliation and it shows not only the N-S trend with both easterly and westerly dips, but also the E-W trend with northerly dips.

Fine-grained massive charnockite, which is dense and dark-colored, typically occurs at Mt. Nokogiri (local name), Mt. Kame-no-se and in the northern part of the main massif. In contrast with the K-feldspar-porphyroblastic charnockite, no inclusion of the gneisses has been found in this rock. Constituent minerals of this rock are the same as those of the K-feldspar porphyroblastic charnockite.

4.3. *Quartz monzonite*

This rock is found at Mt. Kame-no-se, Nunatak 2318 m, Taka-iwa Rock, Mikazuki Rock and on the southernmost cliff of the main massif. The rock is a light gray to brown-colored, homogeneous, medium- to coarse-grained rock. Though mineral composition of the rock changes from that of quartz syenite to quartz monzonite, this rock is designated as quartz monzonite in order to avoid confusion with the massive quartz syenitic rock and the quartz syenitic charnockites. This rock contains clinopyroxene, biotite, K-feldspar, plagioclase and quartz, with or without dark green hornblende. Orthopyroxene has not been found. Sphene is a very common accessory, and apatite, zircon and opaque minerals also accompany. Foliated structure is commonly weak in the rock, but flow-like structure shown by the concentration of mafic minerals is sometimes found. In the case where elongated blocks of the gneisses and charnockites are included, the trend of elongation is also harmonious with these structures. These foliations show the general N-S to NW-SE strike and moderate to high angle dips to the east.

The quartz monzonite intrudes into the fine-grained massive charnockite at Mt. Kame-no-se, where a large number of biotite clots are formed randomly in the latter. This rock is in a difused contact with the K-feldspar-porphyroblastic charnockite on the southernmost cliff of the main massif, and nebulitic and agmatitic structures are developed around the border, and various intermediate lithologic facies between these two rocks were formed here.

At Mikazuki Rock and Taka-iwa Rock, melanocratic bands, a few meters wide, are found in the quartz monzonite. The bands contain many agmatitic and lense-shaped blocks of the banded two-pyroxene biotite gneiss and the two-pyroxene gneiss of the metabasites. In many places, inclusions of the fine-grained massive charnockite with round edges are observed in the quartz monzonite. These phenomena represent various stages of hybridization of the pre-existing rocks by the quartz monzonite.

4.4. Granitic migmatite

The granitic migmatite occurs as dike-like intrusions. The migmatite cuts the fine-grained massive charnockite on the northernmost cliff of the main massif and also cuts the quartz monzonite at Nunatak 2318 m. The migmatite shows agmatitic and schollen structures with a predominant neosome. The paleosomes are composed of amphibolite and biotite gneiss, which is similar to the migmatitic biotite gneiss, and the neosome has the composition varying from granite to quartz diorite. The mineral compositions of the paleosomes are the same as the migmatitic biotite gneiss and amphibolite. A dike-like occurrence of this migmatite suggests that this was emplaced along deep-seated fracture zones.

5. Dike Rocks

5.1. Metamorphosed basic dike rocks

Metamorphosed basic dikes discordantly cut the banded two-pyroxene biotite gneiss, the quartz syenitic charnockites and the quartz monzonite. Some dikes show a distinct schistose structure parallel to the wall of intrusion vent. Mineral constituents are commonly clinopyroxene, biotite, K-feldspar and plagioclase with or without quartz. A dike in the K-feldspar-porphyroblastic charnockite consists of orthopyroxene, clinopyroxene, green hornblende, plagioclase and accessory ore.

5.2. Granites, pegmatite and aplites

Several different stages of emplacement of these dike rocks are recognized by their modes of occurrence.

The charnockitic aplite mentioned before, closely associated with the banded two-pyroxene biotite gneiss, is cut by the K-feldspar porphyroblastic charnockite at the east peak of the Mosuso Hill. This aplite characteristically contains dark gray-colored quartz, K-feldspar (hair perthite) and plagioclase, and has small amounts of orthopyroxene, biotite, zircon and ore mineral. These features resemble those of an acid charnockite.

A gray-colored, fine- to medium-grained biotite granite intrudes into the quartz monzonite. The occurrence of this rock is restricted in the quartz monzonite. This rock seems to be the latest activative of the quartz monzonite.

Pink-colored granite and granitic pegmatite cut all rocks except for the youngest aplitic veins. Pink granite dikes at Mt. Nokogiri altered the adjacent fine-grained massive charnockite into a medium-grained hornblende-rich syenitic rock. A granitic pegmatite at a nunatak in the Ôgi Moraine Field converted the banded two-pyroxene biotite gneiss into the migmatitic biotite gneiss at the contact.

There are the youngest aplite veins which cut all of the rock types mentioned above.

6. Discussion

6.1. Genetic relations of the rocks

On the basis of the field and petrographical observations described above, it is possible to consider the following genetic relations of the plutonic and metamorphic rocks occurring in Massif-A.

The oldest rocks are the metamorphic rocks such as the banded two-pyroxene biotite gneiss with the charnockitic aplite and the associated calc-silicate gneiss, two-pyroxene gneiss and two-pyroxene amphibolite, and are probably also the plutonic rock such as the massive quartz syenitic rock, because they often occur as agmatitic paleosomes or as xenolithic masses in the quartz syenitic charnockites and the quartz monzonite.

Dominant plutonism in Massif-A is represented by intrusions of the quartz syenitic charnockites and the quartz monzonite, among which the former intrusives were followed by the latter one with an intrusive relation. The quartz syenitic charnockites could be subdivided into those of two generations, *i.e.*, the K-feldspar-porphyroblastic charnockite belongs to the older generation, and the fine-grained massive charnockite to the younger one. The quartz monzonite was followed by the gray granite dike which seems to be the latest activate of the quartz monzonite.

The granitic migmatite is the youngest intrusion among the plutonic rocks except for some later dikes of granites and pegmatite and veins of aplite, because it traverses the quartz monzonite.

The metamorphosed basic dikes cut the banded two-pyroxene biotite gneiss, the quartz syenitic charnockites and the quartz monzonite, but their genetic relationships are problematical. Two possibilities of their origin may be considered, one being that they were metamorphosed together with the country rocks after the emplacement of the dikes, and the other being that they were intruded into the country rocks when the country rocks still retained high temperatures and then they were recrystallized under the high temperature conditions. The latter possibility is likely in the present area, since no sign of superposed metamorphism can be observed geologically and petrographically on the country rocks of the metamorphosed basic dikes. Therefore, at least two stages of emplacement of the basic dikes would be distinguishable, that is, the first stage is represented by the dikes in the banded two-pyroxene biotite gneiss and the second stage by those in the quartz syenitic charnockites and the quartz monzonite.

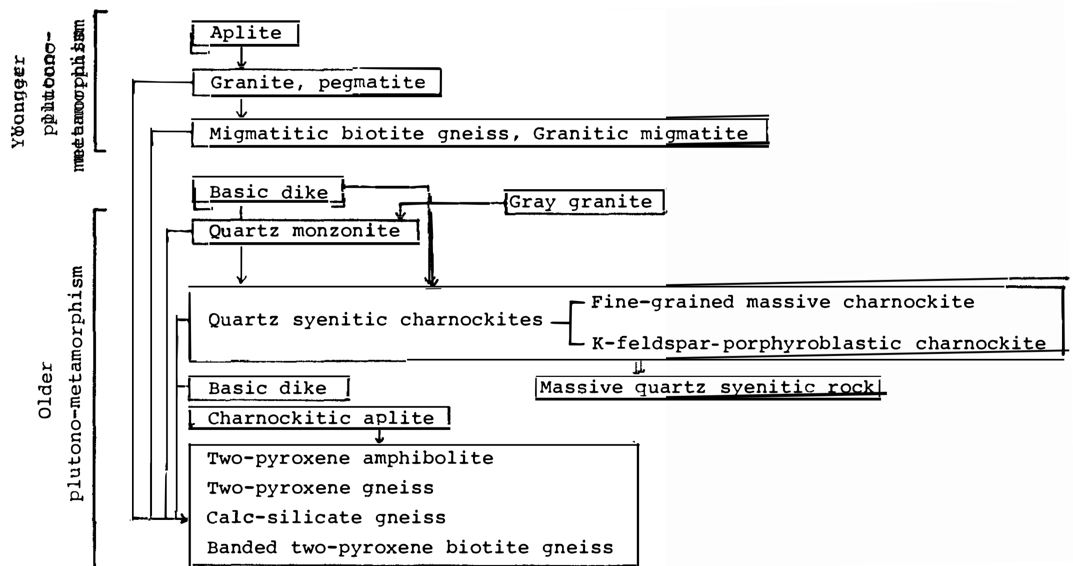

Fig. 3. Mutual relationships among the rock types. Arrows indicate the intrusive relationships observed in field.

Mutual geological relations among the various rocks mentioned above are schematically illustrated in Fig. 3 along with later granite and pegmatite dikes and the latest aplite veins.

6.2. *Metamorphism and related plutonism*

Mineral assemblages of the metamorphic rocks belonging to the oldest rocks

Table 1. Mineral assemblages of the metamorphic rocks.

Group A	Group B
Banded two-pyroxene biotite gneiss	Migmatitic biotite gneiss
(Large masses)	Bi+Kf+Pl+Qz (+Hb)
Op+Cp+Bi+Kf+Pl+Qz (±Hb)	Cp+Bi+Kf+Pl+Qz (±Hb)
Op+Cp+Bi+Hb+Pl+Qz	Gt+Bi+Kf+Pl+Qz
(Agmatitic blocks in quartz syenitic charnockites)	Amphibolite
Op+Cp+Bi+Pl+Qz (±Hb)	Cp+Bi+Hb+Pl
(Agmatitic blocks in quartz monzonite)	Bi+Hb+Pl+Qz
Op+Cp+Bi+Kf+Pl+Qz	Paleosome in granitic migmatite
Cp+Bi+Kf+Pl+Qz (±Hb)	(Biotite gneiss)
Sp+Bi+Pl	Cp+Bi+Kf+Pl+Qz (±Hb)
Calc-silicate gneiss	(Amphibolite)
Gt+Wo+Cp+Sc+Qz (±Pl)	Cp+Bi+Hb+Pl
Wo+Cp+Sc+Pl	Bi+Hb+Kf+Pl+Qz
Wo+Cp+Sc+Cc	
Cp+Sc+Qz (±Hb)	
Metabasites	
(Two-pyroxene gneiss in banded two-pyroxene biotite gneiss)	
Op+Cp+Bi+Hb+Kf+Pl+Qz	Abbreviations: Bi-biotite, Cc-calcite, Cp-clinopyroxene, Gt-garnet, Hb-hornblende, Kf-K-feldspar, Op-orthopyroxene, Pl-plagioclase, Qz-quartz, Sc-scapolite, Sp-green spinel, Wo-wollastonite
(Agmatitic blocks in quartz syenitic charnockites)	
Op+Cp+Bi+Pl+Qz	
(Agmatitic blocks in quartz monzonite)	
Op+Bi+Pl+Qz	
Op+Cp+Bi+Pl+Qz (±Hb)	
Op+Cp+Bi+Pl (±Hb)	
Cp+Bi+Kf+Pl+Qz	
(Two-pyroxene amphibolite)	
Op+Cp+Bi+Hb+Pl	

(Group A) and of the migmatitic biotite gneiss and paleosomes in the granitic migmatite (Group B) are listed in Table 1.

The assemblages of Group A, especially the two-pyroxene assemblages, indicate that the metamorphic grade attained to the granulite facies. As already mentioned, the metamorphic rocks are found as agmatitic blocks, ribbons and lenses in both the quartz syenitic charnockites and the quartz monzonite. These rocks, however, have no indication of conspicuous thermal recrystallization by the enclosing intrusives, and show similar mineral assemblages to those of the metamorphic rocks occurring as large masses. Such evidence suggests that the quartz monzonite as well as the quartz syenitic charnockites were emplaced under the granulite facies conditions.

On the other hand, the metamorphic rocks of Group B lack both two-pyroxene-bearing and orthopyroxene-bearing assemblages. Younger plutonism leading to formation of the migmatitic rocks probably took place under the amphibolite facies conditions.

Therefore, the older and the younger plutono-metamorphic events in Massif-A had different metamorphic conditions as shown in Fig. 3. The rocks of the older and the younger plutono-metamorphism generally correspond to the charnockitic group and the granitic group classified by KIZAKI (1965) in each.

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