Title	Structural and Petrological Studies on the Ryôké Gneiss and Granodiorite Complex of the Yanai District, Southwest Japan.
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Citation	Journal of science of the Hiroshima University. Series C, Geology and mineralogy , 3 (2) : 143 - 213
Issue Date	1960-11-15
DOI	
Self DOI	10.15027/52996
URL	https://ir.lib.hiroshima-u.ac.jp/00052996
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Structural and Petrological Studies on the Ryôké Gneiss and Granodiorite Complex of the Yanai District, Southwest Japan.

By

Yoshihiko OKAMURA*

With 3 Tables, 65 Text-figures, and 9 Plates

ABSTRACT. The Yanai district for the most part consists of the Ryôké metamorphics and granodioritic complexes which are distributed sporadically in the southern margin of the inner zone of Southwest Japan. The metamorphic rocks of the district comprise mostly siliceous banded gneisses, small amounts of semi-pelitic and pelitic rocks, amphibolites and crystalline limestones. The granodioritic rocks are grouped into two generations, *i.e.*, the older and the younger complexes. The former includes autochthonous and parautochthonous granodiorites of Ôbataké, Gokenya, Gamano and Okiura, and the latter intrusive granodiorites and granites of Tōwa, Kibé, Murotsu, etc. It is assumed in field relation and petrography that the banded gneisses have suffered granitization and migmatization and changed gradually into gneissic granodiorites.

Structural features of the banded gneisses and associated granodioritic rocks are presented here in detail. In particular, such features as foliation and lineation in these rocks were measured and their geometry was treated statistically. The folding of banded gneisses is uniform throughout the area, and fold axis *B* coincides with *b*-lineation. The axial planes of folds are generally parallel to each other and considered to coincides with shear plane. The older granodiorites generally exhibit distinct foliation and lineation. It is noteworthy that the trend of older granodiorites is conformable and harmonic with, and locally subconcordant to those of the banded gneisses. The younger granodiorites discordantly cut the structures of the banded gneisses and the older granodiorites.

Petrofabric analyses were made for 22 selected samples, as an important aid to the interpretation of geological structure and geological history of the report area. The results of the petrofabric analysis coincided with the structural megascopic observation. Quartz fabrics of the banded gneisses proper do not show any characteristic patterns or high concentration. As the granitization of the banded gneisses advances, the quartz fabrics exhibit rather higher concentration and roughly monoclinic symmetry. The fabric diagrams of the gneissic granodiorites also show high concentration and symmetry as well as those of the granitized banded gneisess. Mica fabrics are due to the bedding schistosity and show *ac*-girdles. Biotite orientation seems to be related to the known *s*-plane which represents usually shear plane. Biotite orientation of the banded gneisses tends to disperse the concentration as the granitization progresses, and the biotite orientation of the gneissic granodiorites presents a more dispersed girdle, presumably due to increasing mobility of the rocks during the migmatization process.

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I INTRODUCTION

Location: The Yanai district is situated in the southeastern part of Yamaguchi Prefecture, Southwestern Honshû, Japan. The district is mostly occupied by the Ryôké metamorphic and granodioritic rocks. Metamorphic rock of the Ryôké zone is sporadically distributed along the outer border of the Inner Zone of Southwestern Japan, especially in the Tenryûkyô district, the Dando district, the Kasagi district, the Yanai district, etc. The Ryôké zone is composed of the metamorphic rocks derived from the Palaeozoic sediments, as well as of the related older and the younger granodioritic complex. The Yanai district is situated at the western limit of the Ryôké metamorphic zone proper. The regional setting of this area and the portion mapped in detail are shown in fig. 1.

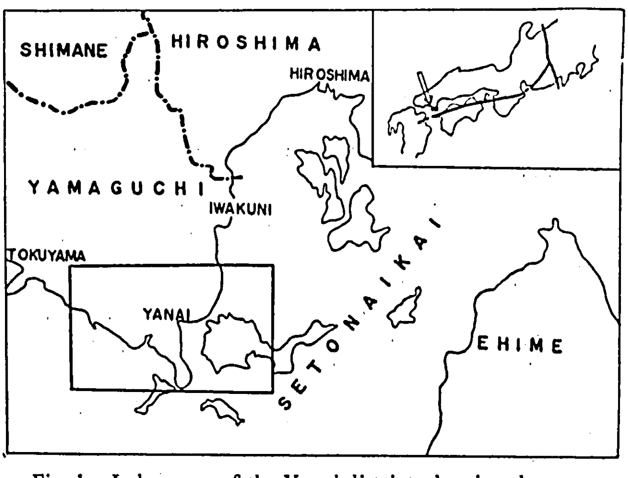

Fig. 1. Index map of the Yanai district, showing the area described in this paper.

Previous works: Since 1890 when HARADA proposed the names Ryôké gneiss and Ryôké schist, which are widely developed in the Ryôké district along the stream of the Misakubo-gawa, a branch of the Tenryû River, a large number of investigations have been made on the Ryôké zone by many Japanese geologists and petrologists. TSUBOI (1929) described the relationship between the schistose granites and the metamorphic rocks. SUGI (1930) mentioned about the injection rocks of the Tsukuba district. IWAO (1936-1939) described the Ryôké metamorphic and granitic rocks in the Tenryûkyô district and the Yanai district, more in detail than any other previous workers. KOIDÉ (1949, 1957) studied the rocks of the Dando district, Aichi Prefecture, especially from the petrological and petrochemical viewpoint. He discriminated two groups of granodioritic intrusives, respectively of older and younger intrusions, and the metamorphic rocks closely associated with those intrusives. The main metamorphic area of the Dando district has been classified by KOIDÉ into the following successive zones in relation to the older metamorphism, namely; the zone of schistose hornfels, the zone of transitional rocks, and the zone of banded gneiss. He concluded that the Dando granodioritic intrusives intruded successively after the older Ryôké metamorphism had been completed. The Ryôké Research Group (1955) assumed that migmatite occurs in the Tenryû River district.

The Yanai district was mapped by AKAGI (1922) and SATÔ (1933), officers of the Geological Survey of Japan, with the results shown on the Geological Maps of Murozumi (1 : 75,000) by the former and Yanaizu (1 : 7,5000) by the latter. IWAO (1936-1939) studied detailed field occurrence and petrography of the metamorphic rocks and granites, and published in many papers the results of his investigations. He concluded that the granites of the region were intruded into the Palaeozoic sediments, followed by the orogenic movements, and produced the "Ryôké injection gneiss" by receiving materials from a magma of the later age. He described that the granites may have been intruded successively under different geological circumstances, and contaminated the sedimentary as well as basic rocks. Since 1951, structural and petrological studies of the Yanai-Iwakuni region have been made with many noticeable results by KOJIMA and his collaborators including the present writer. KOJIMA (1953) stated, "the Ryôké metamorphism is characterized by the prevalence of thermal and metasomatic effect closely related to intense plutonism. Metamorphic zones, commonly found in metamorphic regions of the normal regional metamorphic types such as chlorite, almandine, staurolite and cyanite zones, are entirely absent in the Ryôké metamorphic zone. The metamorphic rocks are characterized by the minerals of thermal-metamorphic type such as andalusite, cordierite, sillimanite, etc." The writer (1957) reported the geology and structure of the Ryôké zone of the Yanai district. For the last several years, NUREKI has studied the structural geology and petrofabrics of the banded gneisses and biotite schists covering the district extending from Yû to Iwakuni.

The sediments or the original rocks of the Ryôké metamorphics are believed to have been derived from the Palaeozoic formations, because of their remarkable lithological similarity to the Palaeozoic formations in the Inner Zone of Southwest Japan. The writer found some Permian fusulinids (*Neoschwagerina* or *Yabeina*) in a lens of nonmetamorphic limestone belonging to the Kuga formation, the name having been proposed by KOJIMA and OKAMURA for the formation of non-metamorphic as well as metamorphic rocks in the Iwakuni-Yanai district. The formation comprises a wide stratigraphic range, including beds up to the Permian, because a southward transition of a Permian beds with increase of metamorphism into biotite schist and banded gneiss is recognized. However, the age of the Ryôké metamorphism and the igneous activity is uncertain. KOBAYASHI (1941) believed that the Ryôké metamorphism and intrusion were the late Mesozoic in age. KOJIMA believed that age of the Ryôké metamorphism to be the early Mesozoic, and his view is now suported by many Japanese geologists.

Scope of the present investigation: The problem about the origin of granite has attracted the attention of many geologists for more than 150 years and is still a highly controversial subject. The magmatic hypothesis and discussions on the origin of most granites have been developed for many years. An opposing hypothesis concerning the development of granite by granitization has been expounded and discussed during the last score of years. It is believed that granitic rocks may originate in more than one way. Some granitic bodies are undoubtedly produced by intrusion of magma into the country rocks, whereas other granites are not intrusives but may be a product of metamorphism of preexisting rocks through the processes of sediments→gneisses→granites. Structural petrology has been applied to the study of regional development of gneisses and granites in order to obtain more precise data concerning the tectonic history of the region and the nature of the rocks, and it has contributed greatly to the understanding of these problems in many parts of the world, especially in Austria, Switzerland, Scotland, New Zealand, Maryland, etc. In our country, after the World War II, many geological and petrological investigations have been made on the metamorphic zones such as the Hidaka zone, the Abukuma zone and the Ryôké zone. As a result, it has been ascertained that granitic rocks produced by granitization occur in several regions. The metamorphic zones of the Japanese Islands should be divided into several orogenic belts which are chronologically separable from each other according to the recent advancement of the geotectonic researches on these regions, although the scale of these zones is very small when compared with the continental orogenic regions mentioned above. The Yanai district which is mostly occupied by the Ryôké metamorphic and granitic rocks is the most favourable field for the study of the problem concerning the development of gneisses and various kinds of granitic rocks.

The present writer has been engaged in the study of geology and rock structure of the Ryôké rocks in the Yanai district since 1951, and has already published some preliminary reports (KOJIMA and OKAMURA 1951, OKAMURA 1957). The geological and structural features of the region were summarized in the previous paper (1957). Although many detailed investigations have been done in the Ryôké zone by many workers, mainly from the geological and petrological point of view, the structural studies, especially the data of petrofabric analyses, are very few. The structural and petrofabric data of the gneisses and the granodioritic rocks will be stressed in the present paper.

In this paper the writer intends 1) to describe the petrographical features, 2) to determine the important megascopic structures, and 3) to discuss micro-petrofabric data as an aid to the interpretation of geologic structure, in order to obtain more precise data concerning the history of metamorphism and igneous activity, and further more concerning the origin of granodiorites.

Acknowledgements: The writer is extremely grateful to Professor George KOJIMA of the Institute of Geology and Mineralogy, Hiroshima University, for his constant guidance and encouragement kindly given to the writer's field and laboratory works, and for reading this manuscript. The writer also wishes to express his gratitude to Professors Sotoji IMAMURA, Yoshirô KINOSAKI, and Yoshiharu UMEGAKI of the University for their continuous guidance and encouragement. Acknowledgements are due to Dr. Masao GORAI of Tokyo University of Education for his valuable suggestions to the study. Thanks are also due to Dr. Kei HIDE and Dr. Terukazu NUREKI of Hiroshima University for their valuable suggestions and criticisms, and to Drs. Hironao YOSHIDA, Tamotsu INOUÉ, Gensei YOSHINO and other members of the Schist Research Group in the Hiroshima University who kindly advised the writer in the course of his work. Finally the writer acknowledges with gratitude that a part of the expense for this research has been defrayed by the Grant in Aid for Scientific Researches from the Ministry of Education, Japan.

II. OUTLINE OF GEOLOGY

General statement: The Ryôké metamorphic zone in the Yanai-Iwakuni region was divided by KOJIMA and OKAMURA (1953) into the following zones from the north to the south, *i.e.*, the non-metamorphic outer zone, the biotite schist zone, and the banded gneiss zone. The metamorphic rocks have an east-west regional trend. The Ryôké granodioritic complex is dominantly distributed on the south of the banded gneiss zone, and no outcrop has been seen in the biotite schist zone and the non-metamorphic zone. The area of the present paper is occupied by rocks of the banded gneiss zone and the granodioritic complex. Beyond the northern limit of the mapped area, the metamorphism gradually declines towards the biotite schist. The boundary between the banded gneiss and the biotite schist zones may lie along the Yû River.

Banded gneiss: The banded gneisses are derived from the Palaeozoic sediments and the basic igneous or pyroclastic rocks. Among the rocks of the banded gneisses siliceous banded gneiss is predominantly distributed, and pelitic and psammitic banded gneisses, limestone, and basic rocks are narrowly distributed as thin layers or lenses. The area under consideration is too small to erect the stratigraphical succession of the deformed banded gneisses.

Granodiorites: The members of the granodioritic complex in the Yanai district include many varieties, and belong to at least two distinct periods of intrusion, *i. e.*, the older migmatitic granodiorites and the younger granodiorites. They are summarized in table 1. It must be noted that many of the older granodioritic rocks of the region have been subjected to orogenic deformation and recrystallization subsequent to its emplacement; therefore, the rocks are generally characterized by the

TABLE 1. GRANODIORITIC ROCKS OF THE YANAI DISTRICT

Older granodiorites	Ôbataké gneissic granodiorite	Occurs as three narrow belts along siliceous banded gneiss; gradually passes into the banded gneiss. Autochthonous migmatite.
	Gokenya gneissic granodiorite	Small irregularly outlined mass enclosed in the Gamano gneissic granodiorite and the banded gneisses. Metasomatic rocks derived from basic igneous rocks.
	Gamano gneissic granodiorite	Forms the great bulk of the older granodioritic complex. Harmonic and subconcordant intrusive to the banded gneiss, characterized by migmatitic as well as magmatic features.
	Okiura gneissic granodiorite	Subordinate in distribution, genetically allied to the Gamano gneissic granodiorite. Fine-grained, markedly foliated and lineated rock.
	Aplite	Sporadically distributed as dikes or massive small intrusives formed after the Gamano mass had been consolidated.
Younger granodiorites	Tôwa granodiorite	Narrowly distributed in the region, but occurs as batholithic masses in the western Setouchi region. Intrusives discordantly cutting the structure of the Gamano and the Okiura masses.
	Kibé granite	Forms a small mass. Porphyritic microcline granite.
	Murotsu granite	Forms small masses. Quite homogeneous in rock facies, Containing xenoliths of banded gneiss. Two-mica granite.
	Fine granite	Occurs as sheets or dikes. Latest intrusion of the Ryôke igneous activity of the region.

gneissic structure.

The area west of the Shimata River, which lies out side of the area in question, is composed of quartz diorite of the Cretaceous, and the Ryôké biotite schist and quartz schist belonging to the zone of biotite schist. The Ryôké biotite schist and quartz schist occur as roof-pendant on the Cretaceous quartz diorite; they suffered contact thermal metamorphism. Along the Shimata River a fault seems to exist.

At the head of the Murozumi Peninsula unmetamorphosed slate and chert of the Paleozoic age are found. It is interesting that these nonmetamorphic Palaeozoic sediments occur near the banded gneiss which represents strong metamorphism, but they are believed to be separated from each other by a hidden fault.

Geological events of the post-Ryôké period: The Cretaceous grnaite (so-called Hiroshima granite) which is broadly distributed as batholiths in the Chûgoku Province is found at the northwestern part of the region; however, it outcrops in a small area in the present mapped area. The Hiroshima granite has intruded into the Gamano gneissic granite, and at Nakayama it was mylonitized near the contact.

A regional uplift, followed by extensive erosion, took place in the later Tertiary. During the period from the Pliocene to the early Quaternary, lava, tuff and tuff breccia of the Setouchi volcanic range covered the erosion surfaces in Ôshima and the Kumagé Peninsula. Diluvial deposits are found on the erosion surfaces at Hizumi and Ikachi, Yanai City, and at Iwata, Hikari City. Alluvial deposits are found in the drainage basins of rivers and creeks.

III. Outline of Petrography

Metamorphic Rocks

As stated above, the zone of banded gneiss is situated to the south of the zone of biotite schist, and passes gradually into the gneissic granodiorites. The banded gneisses were derived from the Palaeozoic sediments and characterized by intense thermal metamorphism accompanied by shearing. The banded gneisses are divided according to the difference in original material into the following six categories, namely; 1) pelitic banded gneiss, 2) psammitic banded gneiss, 3) siliceous banded gneiss, 4) amphibolite, 5) polymetamorphic rocks, and 6) crystalline limestone.

Pelitic and Psammitic Banded Gneisses

Owing to the intense metamorphic recrystallization of banded gneiss, it is difficult to distinguish between the pelitic and the psammitic rocks. The most common type of the banded gneiss derived from pelitic and psammitic rocks is characterized by the fine banded structure due to alternation of white to light grey quartzo-feldspathic layers and dark biotite-rich layers (plate 16-1). Frequently in the quartzo-feldspathic foliae are developed pinches and swells that sometimes lead to the formation of isolated quartzo-feldspathic lenses of several centimeters in width. Locally the rocks are flaggy due to the concentration of biotite flakes parallel to the shear plane. Psammitic banded gneiss is coarser-grained and less fissile.

Mineral compositions of the pelitic and psammitic banded gneisses are given in table 2.

Under the microscope, quartz, plagioclase, potash-feldspar, biotite, muscovite, cordierite, sillimanite and garnet are present as the principal constituents, although varying in amount. The following kinds of banded gneiss are found:

Plagioclase-quartz-biotite banded gneiss
Potash feldspar-plagioclase-quartz-biotite banded gneiss
Plagioclase-quartz-muscovite-biotite banded gneiss
Potash feldspar-plagioclase-quartz-muscovite-biotite banded gneiss
Garnet-plagioclase-quartz-biotite banded gneiss
Garnet-potash feldspar-plagioclase-quartz-muscovite-biotite banded gneiss
Cordierite-plagioclase-quartz-biotite banded gneiss
Cordierite-plagioclase-potash feldspar-quartz-muscovite-biotite banded gneiss
Sillimanite-plagioclase-quartz-biotite banded gneiss
Sillimanite-potash feldspar-plagioclase-quartz-muscovite-biotite banded gneiss
Sillimanite-cordierite-potash feldspar-plagioclase-quartz-biotite banded gneiss

TABLE 2. MINERAL COMPOSITION OF SELECTED ROCKS REPRESENTING THE BANDED GNEISSES AND GRANODIORITE SERIES (VOLUME PERCENT)

	Plagioclase	K-feldspar	Quartz	Biotite	Muscovite	Hornblende	Augite	Cordierite	Sillimanite	Chlorite	Epidote	Garnet	Sphene	Others
							Banded Gneisses							
1	18.3	19.2	36.6	19.8				6.5	0.4					0.2
2	7.3	1.4	54.1	23.1	2.1			1.4	7.6					3.0
3		2.3	93.8	1.7	1.6									0.6
4	2.1		89.4	4.5	3.2									0.8
5	24.1	11.0	57.3	7.2	0.4									
6	39.0	8.0	42.4	8.5	2.1									
							Older Granodiorites							
7	18.1	29.6	33.1	8.2	4.3			5.9	0.3					0.5
8	45.0	8.2	31.0	15.5		0.1								0.2
9	36.6	19.2	34.2	8.5	0.8					0.3				0.4
10	47.5	2.7	28.9	19.5									1.2	0.2
11	64.1	1.4	23.2	6.3		3.8				1.1				0.1
12	53.5	2.6	30.9	12.5								1.2		0.3
13	37.0	16.9	29.3	13.5		3.2								0.1
14	37.9	11.8	39.2	10.9										0.2
15	49.5	0.2	21.2	10.3	4.6	5.9	0.5				6.2	1.6		
16	48.1	9.9	30.1	11.9										
17	56.3	1.2	35.1	7.3							0.1			
18	38.6	18.6	34.5	8.3										
19	22.5	43.6	31.9	0.4	1.3							0.3		
							Younger Granodiorites							
20	40.8	14.1	37.2	7.5		0.4								
21	34.8	34.6	23.8	6.2		0.1								0.5
22	28.6	36.6	26.6	8.2										
23	36.2	23.8	31.2	6.6	2.2									
24	37.7	26.1	33.1	3.1										
25	33.5	27.9	33.4	4.0	1.2									

1. Pelitic banded gneiss, Morihisa, Hizumi, Yanai City.
2. Pelitic banded gneiss, Morigatao, Mitsui, Hikari City.
3. Siliceous banded gneiss, Mt. Kotoishi, Yanai City.
4. Siliceous banded gneiss, Heta, Ôshima Town.
5. Granitized siliceous banded gneiss, Heta, Ôshima Town.
6. Granitized siliceous banded gneiss, Munemitsu, Kuga Town.
7. Ôbataké gneissic granodiorite, Sakagawa, Ôbataké Town.
8. Ôbataké gneissic granodiorite, Ôkubo, Ôbataké Town.
9. Ôbataké gneissic grnodiorite. Tana, Hirao Town.
10. Gokenya gneissic granodiorite, Gokenya, Hikari City,
11. Trondjhemitic rock of Gokenya gneissic granodiorite, Gokenya, Hikari City. Average of 3 specimens.
12. Gamano gneissic granodiorite. Average of 9 specimens.
13. Gamano gneissic hornblende-biotite granodiorite, Taketsuné, Ikachi, Yanai City.
14. Gamano biotite granodiorite (massive). Average of 2 localities.
15. Hybrid rock facies of the Gamano mass, Migama, Ôshima Town.
16. Fine-grained granodiorite of the Gamano mass, Kurokui, Yanai City.
17. Okiura gneissic granodiorite, Heta, Ôshima Town.
18. Okiura gneissic granodiorite, Heta, Ôshima Town.

Sillimanite-cordierite-garnet-potash feldspar-plagioclase-quartz-biotite banded gneiss

As accessory minerals, iron ores, sphene, apatite and zircon are common.

In thin section, the gneissic structure owing to the parallel arrangement of biotite and muscovite flakes is noticeable, and the grain size of quartz and plagioclase is from about 0.2 to 1 millimeter in diameter (plate 20-1). More psammitic portions of these banded gneisses show a more or less granoblastic texture. Segregation veins consisting of larger quartz and feldspar grains are often developed parallel to the schistosity.

Quartz is always an essential constituent. It is usually granular and equidimensional, but many of the large grains are irregular and intricate in shape and are elongated along schistosity. Some of large porphyroblasts carry small inclusions of biotite and muscovite.

Biotite is prominent in quantity and is always found in every type of banded gneiss. The preferred orientation of biotite flakes is remarkable, and in some rocks biotite flakes are bent or fractured. It commonly encloses small crystals of zircon with pleochroic halo. Biotite is pleochroic with: X=pale yellow, Y=dark brown, Z=brown. The refractive index, γ, of 5 specimens ranges from 1.648 to 1.655.

Plagioclase is hypidiomorphic and more or less equidimentional, and sometimes granular or lath-shaped. It ranges from An=20 to An=40. Plagioclase may or may not show albite twins. Zonal structure has not been observed.

Potash-feldspar usually occurs interstitially, and microcline or perthitic structure is absent, although a slight microperthitic structure is recognized in hypidiomorphic crystals.

Cordierite usually occurs as porphyroblast, and is sometimes converted to pinite along cracks. Some of them carry inclusions of sillimanite needles and small rounded crystals of biotite.

Sillimanite forms dense mats of light dirty-brown fibrolite, or separate needles. Fibrolites occur with biotite, and often show the feature of conversion from biotite. Needles of sillimanite are also included in the porphyroblasts of quartz and cordierite. Iwao (1938) reported that cordierite also occurs in the biotite schist zone which is situated to the north of the zone of banded gneiss. That the distribution of cordierite is ubiquitous but sporadical in both the banded gneiss and the biotite schist zones may suggests the development of cordierite depends on the chemical composition of original sediments. On the other hand, sillimanite does not occur in the biotite schist zone, but it appears only in the banded gneiss zone. The coexistence of muscovite, potash-feldspar, sillimanite and cordierite, as has been noticed in the rocks of the Ryôké metamorphic zone by Hayama (1957), is characteristic. Hayama has interpreted that water vapour played an important role as one of essential chemical components during the metamorphism.

Garnet, as an important constituent in some specimens, shows a definite crystalloblastic outline. It is 0.05 to 0.1 millimeters in diameter.

Siliceous Banded Gneiss

Siliceous banded gneisses, derived from banded chert of the Palaeozoic sediments, are most widely developed in this region occurring as thick beds. It is almost always characterized by remarkably regular banded structure due to the alternation of grey to white quartzose layers and black biotite layers (plates 16-3). Owing to the domi-

19. Aplite (average of 3 specimens), Hizumi, Yanai City.
20. Tôwa granodiorite (average of 3 specimens) from Kuga Town.
21. Tôwa granodiorite (average of 7 localities) from Tôwa Town.
22. Kibé granite, Kibé, Yanai City.
23. Murotsu granite, Okumagé, Murotsu Town.
24. Fine-grained biotite granite, Ihonoshô, Yanai City.
25. Fine-grained two-mica granite (dike) Mukuno, Kuga Town.

nance of large quartz grains, the rocks have a greyish luster.

The rocks are chiefly composed of a large amount of quartz, a considerable amount of biotite and subordinate amounts of plagioclase, potash-feldspar, muscovite, cordierite and garnet. As accessory minerals sillimanite, zircon, apatite and iron ores are common. The following kinds of siliceous banded gneiss are found:

Biotite-quartz banded gneiss
Magnetite-biotite-quartz banded gneiss
Muscovite-biotite-quartz banded gneiss
Wollastonite-muscovite-biotite-quartz banded gneiss
Cordierite-biotite-quartz banded gneiss
Sillimanite-bearing cordierite-biotite-quartz banded gneiss
Garnet-sillimanite-cordierite-biotite-quartz banded gneiss
Biotite-plagioclse-quartz banded gneiss
Biotite-muscovite-potash feldspar-quartz banded gneiss
Biotite-muscovite-potash feldspar-plagioclase-quartz banded gneiss
Garnet-cordierite-sillimanite-biotite-potash feldspar-plagioclase-quartz banded gneiss

Mineral compositions of the siliceous banded gneisses are given in table 2. As shown in table 2 the volume percentage of feldspar is variable.

In thin section, layers of biotite or flakes of biotite and muscovite form bands in the matrix which are usually make up of quartz aggregates (plate 20-2).

Quartz is always an essential constituent, forming the matrix of the rocks. The grains range from about 0.1 to 6 millimeters in average diameter. Small or medium grains are more or less granular and equidimentional, while larger grains are irregularly intricate in shape and are commonly elongated parallel to the schistosity. Porphyroblastic quartz shows intense undulatory extinction. IWAO (1938) has reported that porphyroblastic quartz contains in some cases inclusions of small rounded crystals of biotite, plagioclase and magnetite, arranged subparallel to the schistosity.

Biotite forms thin and tabular flakes which have a distinct straight outline. Sometimes it is slightly bent. Biotite is generally well-oriented within the schistosity plane, forming parallel layers. Small flakes are scatterd in quartzose matrix. It is strongly pleochröic with: X = pale straw-yellow, Y = dark brown, Z = yellowish brown with reddish tint. The refractive index, γ, of 4 specimens ranges from 1.650 to 1.654.

Muscovite occurs as laths of medium size in association with biotite, and as small flakes in the quartzose matrix. Muscovite is not abundant and occurs frequently in those rocks containing potash-feldspar.

Cordierite is occasionally an important constituent. It occurs as idiomorphic porphyroblasts of rounded shape, of 0.2 to 0.6 millimeters in diameter, and usually altered to pinite along cracks.

In some specimens the siliceous banded gneisses carry sillimanite in close association with biotite, although in a small quantity. In places wollastonite occurs in varying amount within calcareous lamellae. In many cases plagioclase and potash-feldspar occur in various amounts. These minerals seem to have been produced by the effect of granitization.

Amphibolite

Within the zone of banded gneisses many of amphibolites are sporadically distributed as lenses or thin beds. The amphibolite can be divided into two types from the genetical viewpoint, namely; 1) the one originated in sedimentary beds, perhaps basic or impure calcareous beds, 2) the other originated in basic igneous rocks intruded into the Palaeozoic sediments prior to the metamorphism. These occur within both the banded gneisses and the granodiorite complex.

The amphibolites derived from sedimentary rocks are greenish black, fine-grained and schistose rocks. They occur as thin beds of only a few meters in thickness, and are concordant with the foliation of the banded gneisses. Amphibolite at Hizumi, Yanai City, is alternated with pelitic banded gneiss and calcareous layers. The rock consists mainly of hornblende, plagioclase, diopside, and small amounts of calcite and biotite.

The amphibolites derived from igneous rocks are dark greenish-brown, fine-grained and schistose rocks. They occur as sheet, only a few meters in thickness, within the banded gneiss. An amphibolite dike of about 30 centimeters in width cuts discordantly siliceous banded gneiss at Okuni, Kumagé Peninsula, but its schistosity is parallel to that of the banded gneiss. The rocks consist mainly of plagioclase, hornblende and a small amount of biotite.

The detailed description of the rocks will be given in the paragraph of basic inclusion within granodiorites.

Polymetamorphic Banded Gneiss

Small and irregular masses of banded gneisses occurring sporadically as xenolith near Shimata River to the west of the region, were suffered a thermal metamorphism. The contacts between the banded gneisses and the granodiorites are discordant and sharp. These polymetamorphic rocks retain their original megascopic features; however, the rocks are now more hard, and less fissil, and the degree of preferred orientation of minerals is low.

In thin section, the rocks differ considerably from the banded gneisses proper in many respects. Both polymetamorphic rocks derived from pelitic and siliceous banded gneisses are chiefly composed of quartz, plagioclase, biotite and muscovite. Rocks derived from pelitic gneiss often contain sillimanate. Zircon, iron ores and tourmaline are common accessory minerals. Among these tourmaline is important. The gneissic structure is lost, and the equigranular and hornfelsic texture is well developed.

Limestone

A few crystalline limestone lenses, ranging from only a few meters to about ten meters in thickness, occur interbedded with siliceous and pelitic banded gneisses.

Granitization of the Banded Gneisses

It has been recognized by many investigators that gneisses in many orogenic zones in the world pass gradually into gneissic granodiorites. In the Yanai district, a complete transition from the banded gneisses to the gneissic granodiorites is observed. There are considerable evidences that the banded gneisses were granitized by metasomatism owing to addition of alkali-alumina accompanying igneous activity. The evidences may be classified into two types, namely, petrological and structural, the latter evidence being described in the following pages. These evidences are observed at and near the contact between the banded gneisses and the gneissic granodiorites, and in the part of migmatitic facies of the gneissic granodiorites as well.

Field occurrence: In the granitized pelitic banded gneiss are developed quartzo-feldspathic veins, lenses, and knots concordant with the foliation, so that the rocks shows a migmatitic appearance like a lit-par-lit injection gneiss (plate 16-2). Where the foliation is intensely folded, quartzo-feldspathic veins are abundantly found and occur especially at the crest. The lenses and veins consist, for the most part, of quartz and feldspar accompanied by a small amount of biotite, muscovite and garnet. Some of more feldspathic knots have biotite-rich margins. Thus, they may be regarded as syntectonic pegmatite and aplite. Some quartzo-feldspathic veins form intense ptygmatic folds, but the development of such veins is very rare and local.

Although it has been believed by many workers that siliceous rocks such as chert or quartzite are most resistant to granitization or migmatization, the siliceous banded gneisses of the region are considerably metasomatised and replaced by the materials supplied from the magma, resulting in the granitization products. The siliceous banded gneiss, as a result of granitization, becomes coarser in grain size, and more abundant in feldspar, and the foliation represented by the parallelism of biotitic layers becomes weaker as biotite becomes less important and feldspar increases. At Munemitsu, Kuga Town, and at Ôshima Town quartz diorite produced by the granitization of siliceous banded gneiss retains original folded structure of the banded gneiss (plate 18-1, 2).

In semi-pelitic banded gneiss at Kannon Fall, north of Kôjiro, thin sheets of granitic composition are developed along slip surfaces inclined at high angle to the foliation which might have been formed by flexure of the foliation surface (fig. 2).

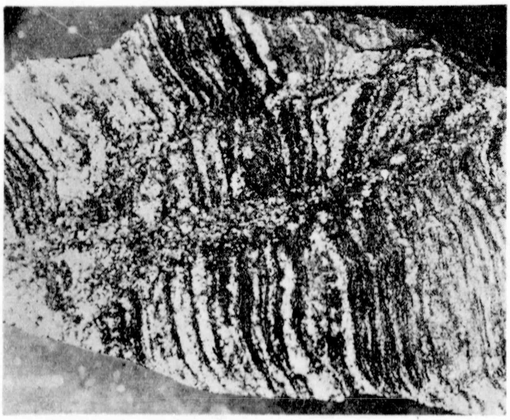

Fig. 2. Granitic rock formed along slip surface in semi-pelitic banded gneiss, Kannon Fall, Kōjiro. × 4/5.

In general, where pelitic banded gneiss has suffered granitization, the rock tends to pass gradually into coarse-grained rocks. Between the pelitic banded gneiss and

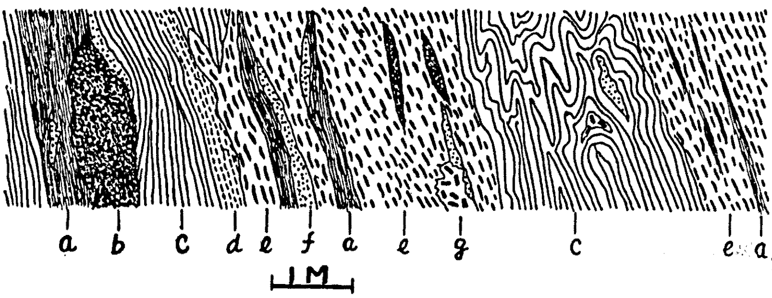

FIG. 3. Migmatitic facies of granitized banded gneiss, Kōjiro.
a: pelitic banded gneiss, b: amphibolite, c: siliceous banded gneiss, d: psammitic banded gneiss, e: gneissic granodiorite, f: aplite, g: pegmatite.

the gneissic granodiorites there occurs no sharp intrursive contact but two rocks pass into each other within the distance of only a few meters. The contact between the siliceous banded gneiss and the gneissic granodiorites can be seen in the central part of the region: gradational change occurs between two rocks and migmatitic rooks are frequently found.

The boundaries between the granitized banded gneisses and the gneissic granodiorites merge into each other, so they cannot often sharply defined. For example, rocks in the transitional zone or in the mixed zone are not readily referrable to either gneissic granodiorites or granitized banded gneisses, the zone extending for hundreds of meters across the area occupied by the Ôbatake gneissic granodiorite. In mapping such an area it is difficult to draw a sharp boundary between them. In many parts of the region, however, a rapid passage, within a distance of scores of centimeters, can be seen between them. At the contacts of the gneissic granodiorites and the banded gneisses is also obserbed in some places a migmatitic facies as shown in fig. 3.

Microscopic observation: Microscopic study of siliceous banded gneisses, from the granitized rocks through the transitional facies to the gneissic granodiorites, shows characteristic changes in texture to be described in the following. One can read microscopically from these rocks various successive stages of granitization. As described above, the siliceous banded gneiss which did not suffered granitization consists mostly of quartzoze matrix and layers of biotite and muscovite. At the incipient stage of granitization, the rock is chiefly composed of quartz, biotite, a small amount of plagioclase and potash-felspar. The plagioclase is albite to oligoclase, and occurs as small idiomorphic crystals of 0.2 to 1.0 millimeters in length, scattered in quartzoze matrix, individual grain of which is elongated along the schistosity. Lamellar twinning after the albite law is common. Potash-feldspar may or may not exist. It is orthoclase and occurs interstitially, sometimes forming irregular veins in quartzoze matrix. Small separate flakes of biotite are dispersed in quartzoze layers. As the granitization abvances, plagioclase increases in quantity as well as in grain size, while quartz decreases.

At a more granitized stage, the rock is composed of large crystals of quartz, plagioclase, biotite and potash-feldspar: as the grain size becomes larger, the amount of plagioclase and potash-feldspar tends to increase progressively, with quartz decreasing. The mineral composition of each stage is shown in table 2. Plagioclase (oligoclase) forms idiomorphic, lath-shaped and slightly rounded crystals. Most of the grains show albit twinning: the twin lamellae have a tendency to lie parallel to the schistosity. Potash-feldspar which is usually not abundant, is interstitial, but some crystals become porphyroblasts. Microcline structure and perthitic intergrowth are not seen. As the granitization abvances, layered arrangement of biotite flakes is disturbed and flakes are dispersed into the matrix. Irregular coarse-grained quartz forms aggregates with plagioclase. In part, fine-grained portion, a relict of the siliceous banded gneiss, remains in coarse-grained aggregates. Occasionally cordierite, silimanite and garnet occur as common accessory minerals.

Although the banded structure of original rocks can be megascopically recognized in rocks of this stage, the rocks are under the microscope indistinguishable from medium-grained granodiorite or quartz diorite. In this way, the granitized banded gneisses progressively grade into the gneissic granodiorite. Fig. 4–A, B, and C show

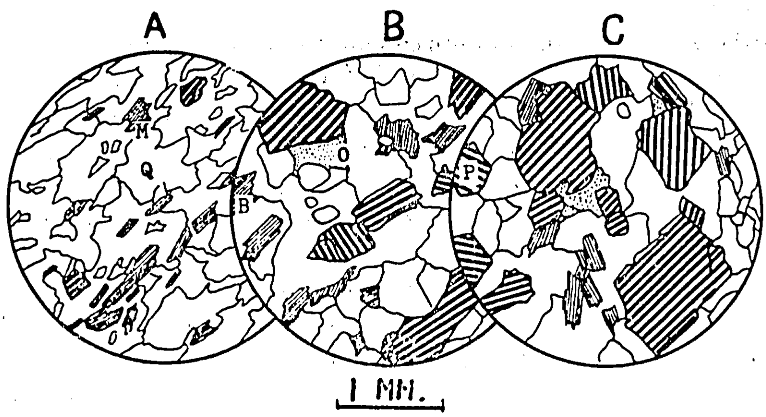

FIG. 4. Microscopic sketches of granitized siliceous banded gneiss, showing granitization process.
P: plagioclase, Q: quartz, B: biotite, M: muscovite, O: orthoclase

the granitization process of the siliceous banded-gneiss. Siliceous banded gneiss at Sakagawa, Hizumi, passes into the Sakagawa type sillimanite-cordierite gneissic granodiorite. The variable mode of siliceous banded gneiss is well expressed in fig. 5 and table 2: most variable properties are the relative proportion of two feldspars on the one hand and the amount of quartz on the other.

The feature described above about the granitization of banded gneisses is not universally applicable throughout the whole area, but it is considerably variable according to their original rocks or to local conditions.

From the preceding petrographical description it is deduced that the granitization

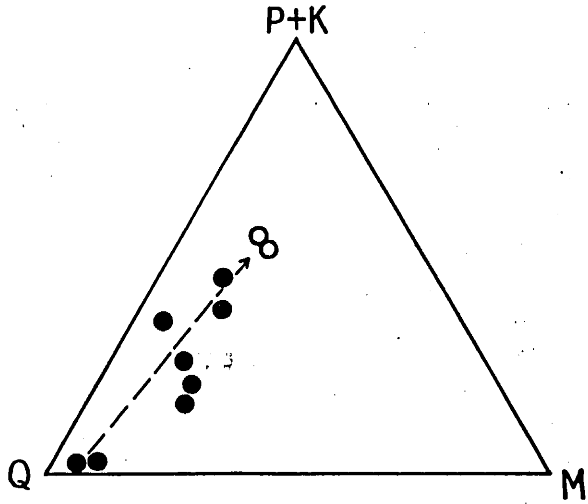

Fig. 5. Triangular diagram showing modal variation in the granitization series of siliceous banded gneiss.
P: plagioclase, K: potash-feldspar, Q: quartz, M: mafic mineral; solid circle: siliceous banded gneiss; open circle: gneissic granodiorite.

of the banded gneisses was a kind of metasomatism due to the addition of alkali-alumina which have replaced the original rocks, and to the disappearance of quartz from the original rocks. In general the granitized banded gneisses differ from the banded gneisses proper in the presence of metasomatic products, *i. e.*, its containing more plagioclase, potash-feldspar and less quartz. With regard to the mineralogical assemblage, the following discrimination is possible: the rock characterized by soda-metasomatism forms plagioclase-quartz-biotite gneiss and the rock predominated in potash-metasomatism forms orthoclase-plagioclase-quartz-biotite gneiss. These rocks are closely associated in the field, the former being widely developed, while the latter only locally. Generally as a result of granitization banded gneisses of various types, *i.e.*, siliceous, pelitic, or psammitic, all become the same sort of gneissic granodioritic rocks which are mainly composed of plagioclase, quartz and less amounts of biotite and potash-feldspar. The granitization process was essentially a metamorphism involving feldspathization, and the granitized banded gneisses cannot be regarded as magmatic products which have mechanically been intruded into banded gneisses. In the granitization process of banded gneisses, however, magmatic contribution may have been important. Progressive change of banded gneisses becomes obvious in approaching magmatic bodies through the migmatitic rocks.

On the areal viewpoint, the granitized banded gneiss tends to develope widely in the central area of the region in question, and is well observed at the following places: Hizumi, Kôjiro, western part of Ôshima, and Tana. They are usually closely associated with the Ôbatake, Gamano and Okiura granodiorites. While in the marginal part of the region the banded gneisses have suffered almost no granitization, and show sharp discordant contacts with the granodiorites, which behave like an intrusive body.

GRANODIORITIC COMPLEX

In the Yanai district, the Ryôké granodoritic complex is distributed within the zone of banded gneiss and in the southern part of the district, but has not been found in the northern part, or in the zone of biotite schist and the zone of non-metamorphic sediments.

As was described in the foregoing paragraph on the geological outline, the granodioritic complex is grouped into two generations, *i. e.;* the older migmatitic granodiorites generally comfomable to the structure of banded gneisses, and the younger intrusive granodiorites and granites discordant with the structures of older rocks.

The older granodiorites are exposed in the greater part of the district under consideration, while the younger intrusives show a narrow distribution. The latter is, however, widely developed in the area to the east of this district, extending into the Takanawa Peninsula, north-western Shikoku. Thus, the Ryôké Zone of the western Setonaikai (Inland Sea) Province is generally occupied by the younger granites, while the older granodioritic rocks occupy only narrowly restricted areas in close relataionship to the banded gneisses.

Older Granodiorites

Ôbatake Gneissic Granodiorite

Field occurrence: As shown in the geological map, the Ôbatake gneissic granodiorite forms three long narrow belts, parallel to the regional trend of the siliceous banded gneiss which runs parallel to the coast line from Yanai to Yû, forming a convex towards S E. A belt extending northeastward from Sakagawa to Nakayama is bent round the anticline of Nakayama. Typical outcrops can be observed along the road from Ôbatake to Hizumi. Starting from the east of Yanai, the central belt extends northeast to Yû for a distance of 8 kilometers. The southern belt runs along the coast. A small mass at Tana seems to be the same type as this. Locally, small lenticular masses are concordantly interbedded between the banded gneisses in the Ôbatake and the Sakagawa areas.

Characteristic features of the field occurrence are as follows:

1) Generally the rock is considerably heterogeneous and variable in grain size, mineral composition and structure, even in single outcrop. Each mass which is separated by belts of siliceous banded gneiss is more or less different in rock facies. As seen in the geological map the belt of siliceous banded gneiss had behaved as septa during the granitization. Gneissic granodiorites separated by these septa are named the Sakagawa type, the Ôkubo type and the Kôjiro type respectively from the north to the south.

2) The relation between the siliceous banded gneiss and the Ôbatake gneissic granodiiorte is always concordant and gradational. No sharp intrusive contact occurs. As mentioned in the paragraph of the banded gneiss, a continuous gradational change

is observed between the banded gneisses and the gneissic granodiorites within various distances. In some localities the contact part is migmatitic as shown in fig. 3. The structural relation of them will be described in the following chapter. The gneissic granodiorite contains well-defined sheets of banded gneisses of about scores of meters in width across the strike with gradational boundaries, forming a mixed zone. A similar transitional zone attaining over one hundred meters is found near the contact with the Tana mass.

3) Existence of layers, schlierens and nebular structures derived from the banded gneisses are remarkable. Besides, each mass contains many basic inclusions.

4) The Ôbatake gneissic granodiorite often contains quartzo-feldspathic bodies, pegmatites and aplite. Pegamtites and aplites occur both as veins or pockets with well-defined, straight or irregular walls and as isolated bodies that often pass into the enclosing gneissic granodiorite. These veins of several centimeters or less in width, often cut sharply across the foliation of the gneissic granodiorite.

Petrography: The mineral composition of various types of the Ôbatake gneissic granodiorite is shown in table 2. The typical gneissic granodiorite consists of plagioclase, quartz and biotite with subordinate potash-feldspar. The Sakagawa type is characterized by the presence of cordierite and sillimanite.

Sakagawa type: Megascopically characteristic is the banded structuure owing to the alternation of dark green mica-rich layers and light quartzo-feldspathic layers (plate 16-4). The rock is coarse-grained and locally characterized by the development of feldspar porphyroblasts. In thin section, granoblastic texture is developed and the gneissosity is mainly controlled by the preferred arrangement of biotite flakes. The rock consists of plagioclase, quartz, potash-feldspar, biotite, muscovite and cordierite. As accessory minerals sillimanite, zircon, apatite and iron ores are common. It must be noticed that cordierite is relatively abundant in the Sakagawa mass, which is enclosed between granitized cordierite-sillimanite-bearing siliceous banded gneiss. That evidently supports the interpretation of granitization origin of the gneissic granodiorite.

Plagioclase (An=30−40) is variable in size even in one section, ranging from 0.5 to 10 millimeters. Small crystals are rounded in shape and large porphyritic crystals are hypidiomorphic. Porphyroblastic plagioclase often contains small rounded biotite, quartz and clouded oligoclase. Zonal structure is rare.

Potash-feldspar is hypdiomorphic and exhibits the microcline structure and slightly microperthitic intergrowth.

Quartz shows an intricate boundary with plagioclase and potash-feldspar. It generally occurs as large patches of several grains commonly as large as plagioclase and potash-feldspar. Large crystals show undulatory extinction.

Biotite occurs as small hypidiomorphic flakes. It is pleochroic with X=light yellow, Y=light brown, Z=brown. The refractive index, γ, determined on 5 samples ranges from 1.654 to 1.657. It abounds in pleochroic haloes around zircon.

Cordierite is developed as polygonal or rounded porphyroblasts which attain 2 millimeters in diameter. It is always altered to muscovite and pinite along cracks (plate 20-3).

Muscovite forms thick tabular crystals with ragged margin, in place of idioblastic outline, and is closely associated with cordierite.

Sillimanite occurs as fibrolite and is usually associated with biotite. In some cases needles of sillimanite are included in quartz and cordierite porphyroblasts.

Ôkubo type: The Ôkubo mass is medium- to coarse-grained and characterized by a remarkable foliation determined by the biotite-rich layers (plate 16-5). Towards the northeast the foliation becomes weaker, while the lineation determined by the parallel orientation of biotite is distinct.

In thin section, the rock consists of quartz, plagioclase, biotite and potash-feldspar in varying amount (plate 20-4). In some specimens, diopsidic augite occurs as an accessory mineral, which may have been derived from calcareous materials in the original sediments. The texture is inequigranular and granoblastic, showing the metamorphic origin. Parallel-arrangement of biotite flakes is distinct.

Plagioclase (An = 32 – 40) occurs as granular crystals varying in grain size. Larger crystals tend to show an idiomorphic outline, while smaller grains tend to be rounded in shape. Twinning is mostly after the albite law or the albite-pericline law and rarely after the carlsbad law. Zonal structure is rare.

Quartz occurs usually as aggregates of interlocking minute grains showing a slight elongation parallel to the foliation. Large porphyro-blastic quartz exhibits marked undulatory extinction.

Potash-feldspar is variable in amount and orthoclase-like. Usually it fills interstices between other minerals. In leucocratic layers that abound in feldspar, potash-feldspar is porphyroblastic and exhibits a slightly microcline structure.

Biotite is thick tabular, occurring as intergrown, and shows subparallel orientation giving gneissic structure to the rock. Pleochroism is X = yellow, Y = brown, Z = dark brown. The refractive index, γ, determined on 5 samples ranges from 1.656 to 1.658.

Zircon, apatite and iron ore are common accessory minerals.

Kôjiro type: The type is fine- to medium-grained and foliation is weak. The rock shows prominent migmatitic appearance in the field.

In thin section, the rock consists chiefly of quartz, plagioclase and biotite with a small amount of potash-feldspar. It has gneissic structure and equigranular texture, with grain size of about 5 millimeters on the average.

Plagioclase (An = 30 – 40) is lath-shaped and hypidiomorphic. It is usually twinned after the albite and the albite-pericline laws and rarely after the carlsbad law.

Quartz forms relatively large patches of several intricate grains, or occurs as lenticular grains parallel to the schistosity.

The property of biotite is similar to that of the Ôbatake type. Biotite commonly encloses small inclusions of zircon accompanied by markedly pleochroic haloes. The pleochroism is X = yellow, Y = brown, Z = brown. The refractive index, γ, determined on 4 samples ranges from 1.655 to 1.657.

Zircon, apatite and iron ores are common accessory minerals.

Gokenya Gneissic Granodiorite

Field occurrence: The Gokenya gneissic granodiorite occurs near Gokenya, Hikari City, as an irregular mass surrounded by the Gamano gneissic granodiorite, occupying an area of about 0.65 square kilometer. Although its outline is irregular like that of an intrusive body, the lineation of the Gokenya mass is parallel to that of surrounding rocks. The contact between the Gokenya gneissic granodiorite and the Gamano gneissic granodiorite is comparatively sharp and irregular as shown in fig. 6. This

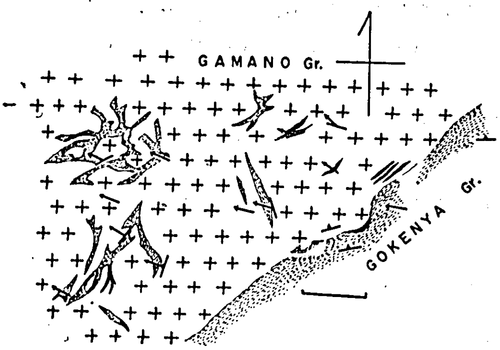

FIG. 6. The contact between the Gokenya gneissic granodiorite and the Gamano gneissic granodiorite. ——: 2m.

suggests that the Gokenya mass was intrdued by the Gamano gneissic granodiorite.

The Gokenya gneissic granodiorite contains many inclusions of siliceous banded gneiss and amphibolite, which form often lenses or thin layers concordant to the foliation of adjacent rocks. The boundary is sharp.

It msut be noticed that sometimes the Gokenya mass contains isolated xenolithlike patches of coarse-grained trondhjemitic rock. They form angular or massive patches, lenses, and veins. The mode of occurrence of them are shown in fig. 7. Their contact with adjacent rocks is often sharp and rarely gradational.

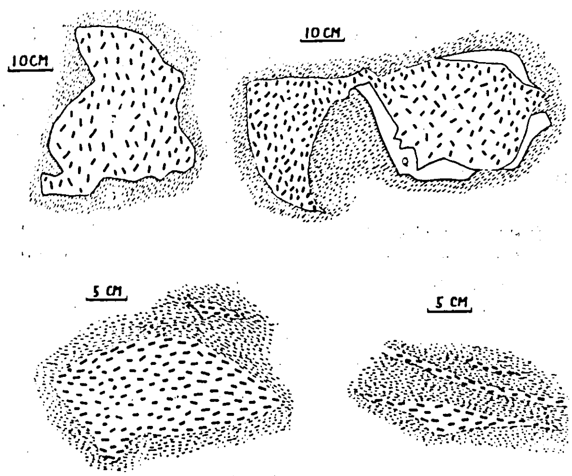

FIG. 7. Mode of occurrence of trondhjemitic patches in the Gokenya gneissic granodiorite. T: trondhjemite, G: Gokenya gneissic granodiorite, Q: quartz.

Petrography:

Gneissic granodiorite: Megascopically the rock is dark-colored, fine-grained and characterized by a remarkable foliation and lineation (plate 16-6). The dark color of the rock is attributed to the presence of a large amount of biotite. Hornblende is usually absent except around the trondhjemite patches. As accessory minerals, sphene, garnet, zircon, iron ore, apatite and potash-feldspar are found. Among these sphene is important.

In thin section, the texture is gneissic rather than granoblastic owing to the preferred orientation of quartz and biotite (plate 20-5).

Among plagioclase are discriminated following two types. The one is An=40–48, hypidiomorphic, which corroded outline against quartz, and the core is clouded; the grain size ranges from 1 to 6 millimeters in length, the carlsbad twin is predominant. The other is An=30–40, fresh, lath-shaped, about 1 millimeter in length, and mostly twinned after the albite law. The latter tends to be arranged parllel to the schistosity. It is inferred that the former represents the relict inherited from the original rock before metamorphism, and that the latter is the recrystallized grain by metamorphism.

Quartz has a lobed outline elongated in the direction of schistosity, and shows undulatory extinction. It is often surrounded by biotite flakes.

Biotite is flaky. Sometimes layers of thin flakes are bent around the grains of quartz and plagioclase. In the western part of the region the biotite shows the effect of chloritization. It is pleochroic with X= pale yellowish-brown, Y=light brown, Z=brown. $\gamma=1.660$ (average of 3 specimens).

Potash-feldspar occurs in a small amount, filling interstices between other minerals. Sometimes myrmekite occurs along the contact with plagioclase.

Sphene is idiomorphic, wedge-shaped with the longer dimension parallel to the schistosity. Sphene is too abundant to be regarded accessory, being a characteristic constituent of the Gokenya mass.

Trondhjemite: Megascopically the rock is coarser-grained and more leucocratic than the surrounding gneissic granodiorite. The lineation determined by the preferred orientation of aggregates of hornblende and biotite is found to be parallel to that of the host.

In thin section the texture is inequigranular and somewhat porphyritic (plate 20-6). The contact which may look sharp in the field is gradational under a microscope. The rock consists mainly of plagioclase and quartz, with subordinate amounts of biotite, hornblende and potash-feldspar. Hornblende is occasionally absent. As accessory minerals, sphene, zircon, and apatite are common.

Plagioclase is hypidiomorphic, varying from small granular to porphyritic crystals as 10 millimeters. Large crystals show the polysynthetic albite twinning, occasionally combined with the carlsbad twinning. Larger crystals are zoned, showing clear albitic rim (An=34) grading into somewhat more calcic, sericitized cores (An=46). Small crystals are fresh, more or less granular, and twinned after the albite law. In some cases the plagioclase is replaced by fresh albitic plagioclase.

Quartz is irregular in shape and fills interstices between other minerals. It usually shows undulatory extinction. In part, large patches of several intricate grains are found, attaining 1 centimeter in diameter.

Biotite is hypidiomorphic and often intergrown with others. It is pleochroic with X=pale yellow, Y= light brown, and Z=reddish brown. $\gamma=1.658$. The trains of biotite flakes are bent around grains of plagioclase and quartz. Quartz and plagioclase show occasionally cataclastic texture. These suggest that mylonitic deformation took place during the last stage of crystallization.

Hornblende is hypidiomorphic. Larger crystlas which attain about 0.5 centimeter in length are prismatic with subhedral outlines. Some crystals include small grains of quartz and plagioclase poikilitically. Hornblende is aggregated with biotite and occasionally intergrown with plagioclase. It is pleochroic with X=yellowish brown, Y=light brown, and Z=bluish green. $\alpha=1.656$, $\gamma=1.681$, and $\gamma-\beta=0.025$. 2V about X=87°. $c \wedge Z=22°$

Potash-feldspar occurs as an interstitial mineral. Intricate grains form patches aggregated with plagioclase.

Sphene is wedge-shaped. It shows corroded boundaries against other constituent minerals and has a tendency to accompany mafic minerals.

Origin of the trondhjemitic patches: Two possible origins of trondhjemitic patches may be considered: 1) that they are xenoliths mechanically captured by the intruding Gokenya mass prior to the metamorphism, or that 2) they have been formed as a result of granitization of enclosing rock. Judging from the field evidences and the microscopical observations, the Gokenya mass must be regarded as has been produced by granitization of basic igneous rock. The field occurrence of the trondhjemites shows every stage of granitization ranging between dioritic and granitic compositions. Small vague lenses or schlierens found around and near the trondhjemite patches show incipient features of "trondhjemitization". Microscopic observations support the granitization hypothesis, *e. g.*, mantle structure and glomeroporphyritic intergrowth of plagioclase, corrosion of sphene within the trondhjemite, and more granitic texture of the trondhjemite than the enclosing rocks.

Judging from the points above mentioned, the xenolith-like trondhjemites may be regarded as a product of more abvanced stage of granitization which acted on the Gokenya mass. The formation of trondhjemite must be due to local concentration of sialic materials, accompanied by some basification effecting the formation of hornblende.

Gamano Gneissic Granodiorite

Field occurrence: The Gamano gneissic granodiorite is most widely exposed in this region. It is a composite intrusive mass. According to the mineralogical composition and the field appearance, it may be divided into the following types, namely; gneissic biotite granodiorite, gneissic hornblende-biotite granodiorite, fine-grained granodiorite, massive biotite granodiorite, and hybrid rock resulted from granitization of basic rocks. The distribution of these rocks is shown in the geological map. Gneissic biotite granodiorite is the most predominant type of the Gamano mass, and shows wide distribution. It also occurs as isolated lens-like masses, scores of meters thick, interbedded within siliceous banded gneiss. Gneissic hornblende-biotite grandiorite occupies the northern area extending from Taketsune to Ôsato, Hizumi, Yanai City. Fine-grained granodioritic facies is found in a few localities as xenolith-like masses, of about 10 meters in diameter, which grade into a coarse-grained granodiorite through an aplitic facies. The facies may probably be attributed to the heterogeneity of the Gamano mass. Massive granodiorite is distributed in the western area near the Shimata River. The hybrid rocks are developed in close association with basic rocks locally, *e. g.*, at Shimata, Jônan and the northwestern part of Ôshima Island.

The most remarkable structural feature of these rock types is the general conformity with regard to the foliation and the lineation between each other. The boundary between them is gradational. Typical outcrops are observed in the Kuga, Mukuno and Komatsu areas along the northwestern coast of Ôshima.

Characteristic features of field occurrence are as follows:

1) As a result of migmatization, the Gamano gneissic granodiorite is highly variable in composition, grain size and structure even in one outcrop (plate 18-5). In general, the rock is coarse- to medium-grained. In some places fine-grained granodiorite is contained as irregular masses. Occasionally, a porphyritic facies with feldspar porphyroblasts is developed.

2) Contact relation between the gneissic granodiorite and the banded gneisses is very interesting. Field behaviour of the Gamano gneissic granodiorite is in general very similar to that of the Ôbatake mass: the gneissic granodiorite and the banded gneisses gradually pass into each other over a few meters, and migmatitic facies is found at the junction in the central and the southern areas of the region (plate 18-6), while at the same locality, the Gamano gneissic granodioite comes occasionally in contact discordantly with the granitized banded gneiss, as is usually the case for intusive bodies, accompanied with intervening coarse-grained and non-gneissic aplitic facies. The contact is usually interlocking without chilled margin. In the adjoining banded gneisses can be found no effects of thermal metamorphism. At the western and eastern margins and in the northern part of the region the Gamano granodiorite shows discordant, intrusive contact with the banded gneisses. Thick veins or dikes of aplitic granodiorite cut sharply the siliceous banded gneiss in the Kandori Cape, Hikari City, and in the western part of Hizumi.

3) Numerous thin layers, lenses and schlierens of banded gneisses occur within the Gamano mass in a manner similar to that in the Ôbatake mass. The boundary is usually sharp, but sometimes gradational, resulting in a mixed zone. Nebulitic or ghost structure of banded gneisses is often observed (plate 18-4).

4) Inclusions of basic rocks are abundant. They are gradually converted into the hybrid rock mentioned above. They will be described in detail bellow.

5) Pegmatite and aplite occur both as veins with well-defined, straight or irregular walls, as pinching and swelling veins, and as irregularly shaped, isolated bodies that often pass into the surrounding gneissic granodiorite. The relation between pegmatites and aplites are complicated. Both aplites and pegmatites may be regarded as differentiated within the Gamano mass.

Petrography: Mineral composition of each rock type is given in table 2.

Gneissic biotite granodiorite: The gneissic biotite granodiorite is the most prominent member of the Gamano mass, occupying more than two-thirds of the area.

Megascopically the rock is usually grey in color and medium- to coarse-grained, showing marked gneissic structure (plate 17-2). Locally the rock appears porphyritic due to the presence of feldspar porphyroblasts.

In thin section, the texture is inequigranular, and sometimes porphyritic (plate 20-7). The rock is mainly composed of plagioclase, quartz and biotite, with a small amount of potash-feldspar. Hornblende rarely occurs as an accessory mineral, which may probably be attributed to contamination of basic rocks. As accessory minerals, zircon, apatite, iron ore and rarely allanite are present.

Plagioclase (An=30−40) is hypidiomorphic or granular: larger crystals have idiomorphic outlines whereas smaller grains are more or less rounded. Albite twinning is most common, sometimes it occurs combined with the pericline and/or carlsbad twinning, the latter of which is rare. Some large porphyroblastic crystals are slightly zoned with albitic rims grading into somewhat more calcic cores. In general, smaller grains are fresh and rounded in shape, while larger crystals are zoned, affected by saussuritization, and contain minute inclusions of biotite and plagioclase.

Quartz occurs as irregularly shaped crystals varying in grain size. Someimes it forms patches, as large as several millimeters in diameter, being composed of intricate fine grains. Some quartz fills interstices between other minerals. Undulatory extinction is common.

Biotite is hypidiomorphic, thick tabular with ragged margin, or with a distinct straight outline. Biotite usualy occurs as patches composed of intergrown, predominantly subparallel flakes. It is pleochroic with X=pale yellow, Y=brown, and Z=brown. The average refractive index, γ, of 5 specimens is 1.658 ± 0.002.

Potash-feldspar occurs in a small amount as an interstitial mineral, sometimes as large, well-formed crystals, not showing microcline structure or perthitic intergrowth.

Gneissic hornblende-biotite granodiorite: Megascopically the rock is grey in colour, coarse-grained, with remarkable gneissic structure due to the preferred orientation of mafic minerals.

Usually the rock is very similar in appearance to the gneissic biotite granodiorite above described textural and mineralogical properties, except for the presence of hornblende. The rock consists of quartz, plagioclase, potash-feldspar and small amounts of biotite and hornblende.

Plagioclase (An=32−40) is short prismatic and hypidiomorphic. The albite twinning is occasionally combined with the carlsbad twinning. Large crystals are turbid, being altered to sericite. It contains fine granular biotite, plagioclase and quartz. Zonal structure is rare.

Quartz is irregular in shape and occurs interstitially. It forms sometimes large patches consisting of several grains. Undulatory extinction is common.

Potash-feldspar occurs as large, hypidiomorphic crystals, showing microcline structure.

Hornblende occurs as hypidiomorphic or ill-formed crystals. It forms sometimes mafic aggregates with biotite, which defines the gneissic structure. Small patches of cummingtonitic amphibole are enclosed in hornblende in parallel intergrowth with sharp boundaries. The pleochroism is: X=brownish yellow to greenish yellow, Y=brownish green, and Z=brownish green. 2V about X=77°. $c \wedge Z = 16°$.

Biotite is thick, hypidiomorphic, tabular in form. Trains of biotite aggregates show directional arrangement. It is pleochroic with X=yellow, Y=brown, and Z=brown.

As accessory minerals zircon, apatite and iron ore are common.

Fine-grained granodiorite: Megascopically the rock is fine grained, dark greyish in color, free from gneissosity and is homogeneous.

In thin section, the rock is composed mainly of quartz, plagioclase, biotite and potash-feldspar. Zircon, apatite, sphene and opaque minerals are common accessory minerals. The texture is granoblastic and equigranular unlike that of the gneissic biotite granodiorite. The grain size is 1 millimeter in average diameter.

Plagioclase is hypidiomorphic, showing mostly the albite or albite-pericline twinning. The carlsbad twinning is rare. In large crystals muscovite fills up cracks. Sometimes it shows corroded boundary against potash-feldspar and quartz. Zonal structure is rare.

Quartz is allotriomorphic and forms intricate aggregates. Undulatory extinction is common.

Potash-feldspar is rather subordinate, and is allotriomorphic and irregular in shape. It does not exhibit microcline structure or perthite intergrowth. Rarely myrmekite is formed inside of potash-feldspar along the contact with plagioclase.

Biotite forms thick plates, often showing glomeroporphyritic intergrowth. Frequently it contains small apatite and small zircon with pleochroic haloes. The pleochroism is: X=straw-yellow, Y=dark brown, and Z=dark brown. $\gamma=1.656$.

Massive biotite granodiorite: The gneissic granodiorite passes gradually into massive granodiorite towards the west of the region. The boundary between them can not be sharply defined on the map, as both rock types merge gradually into each other.

Megascopically the rock is coarse-grained, free from gneissosity, and homogeneous; it is somewhat porphyritic due to the development of porphyroblasts of feldspar up to 1 centimeter or more in diameter.

In thin section the rock consists chiefly of plagioclase, quartz, biotite and variable amounts of potash-feldspar. Apatite, zircon and iron ores are common accessory minerals. The textuture is porphyritic, partially granoblastic.

Plagioclase (An=30−40) is hypidiomorphic, varying in grain size. Large crystls suffered saussuritization at the core. Sometimes normal zonal structure is developed. The albite twinning is common, occasionally combined with the carlsbad twinning.

Quartz tends to form pools (10 millimeters in diameter), aggregates of fine irregular crystals.

Potash-feldspar which is allotriomorphic occurs in varying amounts. Perthitic intergrowth and microcline structure are not seen. Occasionally large, idiomorphic crystals are developed. They are often twinned after the carlsbad law.

Biotite is hypidiomorphic, and thick tabular. Trains of biotite tend to surround pools of quartz and large crystals of plagioclase. Optical properties are very similar to those of the gneissic biotite granodiorite.

Quartz diorite-tonalite (hybrid rock): Hybrid rock is formed by migmatization of basic rocks which are closely associated with the gneissic granodiorite. The rock varies in mineral composition from quartz diorite to tonalite. Here, the writer intends to describe the hybrid rock occurring along the coast from Kuga to Mukuno.

Megascopically the rock is usually dark-colored, medium- to coarse-grained, and characterized by the gneissosity due to the preferred orientation of mafic minerals. The rock is relatively homogneous in megascopic appearance, when compared with the margin of the basic rocks which are highly variable in mode of occurrence.

The rock is mainly composed of plagioclase, quartz, biotite, hornblende and subordinate amounts of muscovite and chlorite. Sometimes small amounts of pyroxene, epidote and calcite occur. As accessory minerals, zircon, apatite and iron ores are common. The mineral compositions of several specimens are given in table 2. The rock shows inequigranular texture, but in part equigranular and granoblastic, and is variable in mineral assemblage.

Plagioclase (An=42−48) is more calcic than the surrounding Gamano gneissic granodiorite proper. It occurs as small to medium-grained (0.5−5 millimeters), granular crystals. Some large hypidiomorphic crystals contain small quartz and saussuritized plagioclase. Most of plagioclase crystals show the albite twinning, occasionally combined with the pericline twinning. The carlsbad twinning is rare.

Quartz is irregular in outline, occurring as aggregates with plagioclase, and partially fills interstices. Sometimes fine, opaque inclusions occur. Undulatory extinction is common.

Hornblende occurs as irregular crystals of variable amount. Usually hornblende, which shows glomeroporphyritic intergrowth, is associated with biotite. Sometimes it is altered to biotite or chlorite. Pleochroism: X = yellowish brown, Y = brownish green, and Z = bluish brown. 2V about X = 84° $c \wedge Z = 18°$.

Biotite forms thick tabular crystals with ragged margin. It is partially altered to chlorite. Inclusions are commonly small zircon and apatite crystals. Pleochroism; X = pale yellow, Y = brown, Z = reddish -brown. The average refractive index, γ, of 3 samples is 1.655 ± 0.002.

Muscovite forms crystals with irregular outline. Epidote also occurs locally as small grains closely associated with hornblende and biotite. Occasionally calcite seams replace the plagioclase.

Okiura Gneissic Granodiorite

Field occurrence: The Okiura gneissic granodiorite is distributed to the south of the Gamano gneissic granodiorite, extending from Okiura, Ôshima, to the south of Saga, Kumage Peninsula. The granodiorite developed in the latter locality are very similar in field appearance, therefore it may represent the continuation of the Okiura mass, although these two areas are separated by the sea. It is observed that this mass gradually changes into the Gamano mass along the coast from Heta to Yokomi, Okiura. In the field, however, the Okiura granodiorite is distinguished from the Gamano mass by its lithological appearance, although its characteristic features are very similar to those of the Gamano gneissic granodiorite (plate 18-3).

Petrography: The rock is fine- to medium-grained and grayish in color (plate 17-3). It exhibits banded structure owing to the alternation of melanocratic and leucocratic layers. At the coast of Heta it is heterogeneous, with banding or foliation due to the alternation of thin layers (20∼30 centimeters in width) of coarser and finer-grained facies. Iwao (1936) attributed this structure to the injection of younger fine-grained granite into older coarse-grained one.

Mineral composition and proportion differ more or less seam by seam of the gneissic structure; however, the rock is chiefly composed of quartz, plagioclase, biotite and variable amount of potash-feldspar. Some parts of the mass are represented by granitic rock containing much potash-feldspar. In the area south of Saga the rock carries abundant almandine garnet.

In thin section, the texture is more equigranular than the Gamano gneissic granodiorite (plate 20-8), although gneissic structure is considerably developed.

Quartz occurs as allotriomorphic crystals, occasionally with irregular, intricate outline. Undulatory extinction is common. In rocks with marked lineation quartz grains are slightly elongated parallel to the gneissosity.

Plagioclase (An = 30 – 40) is hypidiomorphic to idiomorphic, and shows mostly the albite twinning. Smaller grains are rounded and generally twinned after the albite law. Rarely the carlsbad twinning is observed. Prismatic crystals show preferred orientation parallel to the gneissosity. Large untwinned crystals are occasionally zoned normally. At Izui plagioclase is partially sericitized.

Potash-feldspar usually fills interstices. In rocks of more granitic composition potash-feldspar forms large, well-formed crystals, sometimes including fine grains of plagioclase and quartz. Perthitic intergrowth or microcline structure are not observed. Myrmekitic intergrowth is developed inside of potash feldspar along its contact with plagioclase and quartz.

Biotite forms hypidiomorphic, fresh, thick tabular crystals with ragged edges, showing more or less directional arrangement. It usually contains minute grains of zircon and apatite, and is sometimes chloritized. It is pleochroic with X = yellow, Y = brown, and Z = brown with reddish tinge. The average refractive index, γ, of 3 samples is 1.658 ± 0.002. Zircon, apatite, garnet and iron ores are common.

accessory minerals.

Aplite and Pegmatite

The older granodiorites were accompanied by many aplites and pegmatites, which vary considerably in mode of occurrence. These are distinguished by the field occurrences from the aplite or pegmatite which are segregated from the older granodiorite prior to the consolidation of host rocks. They represent the latest expression of the older igneous activity.

Aplite: Aplites occur as dikes with straight or irregular boundaries, or as isolated masses of irregular shape. The dikes, scores of centimeters wide, often sharply cut the gneissosity of banded gneisses and granodiorites (plate 19-6). In the central area of the region, these aplites occasionally pass into pegmatitic facies. Irregular-shaped massive aplites of several hundred meters in diameter are distributed in the central part of the district, *viz.* Hizumi, Mt. Kotoishi and Nakayama. In the marginal parts of the district most of aplites occur as fissure-filling dikes.

Megascopically the aplites are fine-grained, commonly homogeneous, and free from gneissosity. At Yokogawa an aplite dike (specimen 57102805) about 1 meter wide cuts discordantly siliceous banded gneiss, and the foliation defined by parallel arrangement of biotite is developed oblique to the boundary plane. In some localities lumps of garnet, with or without biotite and chlorite, of about 1 centimeter in diameter, are abundantly developed.

The rock is mostly composed of potash-feldspar, quartz, plagioclase, and small amounts of biotite and muscovite. The average mineral composition of irregular aplites is given in table 2. A mass on the south of Yanai City contains occasionally abundant garnet. An irregular mass at Nakayama, Hizumi, contains cordierite which is converted to muscovite. A dike at Ayugaeri, Hikari City, contains fibrolitic sillimanite. These rocks show hypidiomorphic, equigranular texture. It must be noted that potash-feldspar shows perthitic intergrowth and encloses small grains of plagioclase and quartz.

Pegmatite: So far as the writer's field survey is concerned, only one dike of pegmatite can be found within the Gamano gneissic granodiorite at Ishii, Yanai City. It attains about 20 meters in width, but cannot be traced along the strike because of heavy weathering. The rock consists of plagioclase, potash-feldspar, quartz, muscovite and biotite. Sometimes clots of granet, a few centimeters wide, occur. It has been known that uranium-bearing minerals such as autunite, etc., are contained in the rock.

BASIC INCLUSIONS

Basic inclusions which are ubiquitously found in the Ryôké granodioritic complex have been studied by several investigators. So-called basic rock in the area of this report corresponds to fine-grained, compact, dark greenish to brownish rocks. Basic rock in the area was investigated in detail by IWAO from 1936 to 1939. He divided the basic rocks according to mineral assemblage into the following three classes, *i.e.*;

1) diabase~fine-grained hornblende gabbro~gabbroic diorite, 2) argillo-calcareous hornfels derived from sedimentary rocks, and 3) hornblende-biotite-plagioclase granulite derived from diabasic rocks. According to IWAO, these rocks were thermally metamorphosed and assimilated by some granite magma, resulting in contamination facies.

The present writer, however, divides the basic rocks according to their mineral assemblage and origin into the following three types:

1) Inclusion derived from pelitic banded gneiss in which mafic minerals are concentrated.

2) Amphibolite derived from basic igneous rocks and calcareous or basic sedimentary rocks.

3) Metadiabase which was intruded prior to the intrusion of the older granodiorites.

Despite of abundance of basic inclusions, fresh samples which are fit for microscopic observation are few because of intense weathering. Seventy-eight thin sections of these basic rocks, examined by the writer, are classified as follows:

Rock name	Number of specimen	Percentage
Pelitic banded gneiss	13	19%
Amphibolite	38	56%
Metadiabase	17	25%

Field occurrence: Most of basic inclusions derived from pelitic banded gneiss are found throughout the older granodiorites. They occur as lenticular or ovoid schlieren, measuring from several centimeters to a few meters in length and from a few centimeters to scores of centimeters in width. Usually the boundary with the granodiorite is sharply defined, but occasionally not so sharp, showing gradational but rapid merging of two rocks (plate 19-2, 5).

Amphibolites are also found throghout the older granodiorite. There is a strong tendency of amphibolites to be very abundant when associated with hybrid rocks which represent one facies of the Gamano granodiorites. The shape of amphibolites is variable, being ovoid, lenticular, dike-like or occurring as irregular mass, measuring from seveal centimeters to a few hundred meters in width.

Metadiabase occurs as small masses or subangular blocks, sometimes as large as scores of meters in diameter. They are abundant in the northwestern part of Ôshima Island, often accompanied by various granitized rocks, which pass into the hybrid rock facies of the gneissic granodiorite. The rocks are often traversed by many clean-cut veins or irregular network veins of aplite (plate 19-3).

Petrography:

Inclusions derived from pelitic banded gneiss: Megascopically the inclusions are brownish-black and fine-grained, characterized by remarkable schistosity. The rock consists chiefly of plagioclase, quartz and a relatively large amount of biotite, exhibiting typical gneissic structure. The rock is, petrographically, quite similar to the pelitic banded gneiss which shows concentration of biotite, that suggesting the inclusions to be the relict of pelitic banded gneiss.

Amphibolite: Megascopically, the rock is compact, dark greenish, fine-grained and schistose. Sometimes porphyroblastic biotite and plagioclase are developed. The rock is mostly composed of plagioclase, hornblende, and small amounts of biotite and quartz. Rarely, cummingtonite, hypersthene, diopsidic pyroxene and epidote occur as accessory minerals. Mineral composition of a few samples is shown in table 3.

TABLE 3. MINERAL COMPOSITION FOR SELECTED ROCKS REPRESENTING THE GRANITIZATION SERIES OF BASIC ROCKS (VOLUME PERCENT)

	Plagioclase	K-feldspar	Quartz	Biotite	Muscovite	Hornblende	Chlorite	Opaque Mineral	etc.
1	46.9	—	11.3	27.3	—	14.2	0.3	—	—
2	57.0	—	30.8	11.6	—	—	0.6	—	—
3	45.4	0.7	36.6	16.6	—	—	0.7	—	—
4	49.9	—	7.9	—	3.6	33.1	2.8	2.3	0.4
5	54.1	—	—	1.8	—	40.8	—	3.3	—
6	62.3	—	16.9	2.8	1.4	8.0	7.3	—	1.3
7	60.0	—	19.4	9.1	—	11.1	0.4	—	—
8	48.8	—	19.1	26.1	—	5.2	—	—	0.8
9	42.1	14.6	38.6	3.9	0.4	—	0.4	—	—

1. Amphibolite, Ihoki, Hikari City.
2. Granitized amphibolite, Granitized portion of no. 1, Ihoki, Hikari City.
3. More granitized amphibolite, Ihoki, Hikari City.
4. Metadiabasic rock, on the coast from Kuga to Mukuno.
5. Metadiabasic rock, Mukuno, Kuga Town.
6. Granitized facies of no. 5, Mukno.
7. Amphibolite which is more or less granitized, Jōnan, Tabuse Town.
8. Granitized amphibolite of no. 7, Jōnan.
9. Pegmatite facies of no.7. Jōnan.

As accessory minerals apatite, sphene and opaque minerals are common. Nematoblastic texture is well developed (plate 19-2).

Plagioclase is idiomorphic and lath-shaped, less than 0.4 millimeters long, showing twin-lamellae after either the albite or the carlsbad law, and its orientation prefers the direction of the schistosity. Large crystals which are occasionally twinned after the carlsbad law show usual corroded boundaty against quartz and fresh plagioclase, and their cores are sericitized or turbid with minute alteration products. In porphyroblastic hypidiomorphic crystals turbid lath-shaped core is enclosed by thin and fresh sodic mantle. These characters of texture seem to show their igneous origin.

Hornblende occurs usually as hypidiomorphic, rounded-prismatic crystals. The pleochroism is X = pale yellowish brown, Y = light greenish brown, and Z = brownish green. $\alpha = 1.663$; $\gamma = 1.694$. 2V about X = 74°. $c \wedge Z = 22°$.

Biotite forms hypidiomorphic, thick tabular crystals with ragged margin and aggregates with hornblende. The pleochroism is X = pale yellow, Y = brown, and Z = brown. Sometimes porphyroblastic biotite occurs sporadically. It is reddish-brown, hypidiomorphic, thick tabular, and slightly poikilitic.

Quartz occurs in small amount as elongated granular crystals.

Amphibolite derived from sedimentary rocks rarely contains diopsidic pyroxene and epidote.

Metadiabase: Megascopically the rock is dark-colored, fine-grained, compact, massive, and free from schistosity.

The rock is mainly composed of hornblende, plagioclase and small amounts of quartz and biotite. Sometimes cummingtonite and hypersthene occur in close association with hornblende. Apatite, opaque ores and sphene are common accessory minerals. Mineral composition is given in table 3. In thin section the rock is equigranular hornfelsic, and slightly gneissic in fabric (plate 21-1).

Plagioclase is granular or lath-shaped, 0.4 to 0.6 millimter long. Twins after the albite and the carlsbad laws are common. Small crystals are always clear, while large crystals sometimes show mantle structure, *i. e.*, lath-shaped, turdid and sericitized core is surrounded by thin shell which is more sodic in composition than the core. The cores seem to be the relict of original rocks.

Hornblende is hypidiomorphic, short prismatic, about 0.4 millimeter long. Sometimes it is associated with cummingtonite and hypersthene. Iwao (1937, 1938) reported that three minerals are arrange forming separate zones, namely, hypersthenes, cummingtonitic amphiboles and common hornblendes, from the inside to the outside. He said that the textural relation of the cummingtonitic amphibole to the associated hypersthene and to the common hornblende suggests a replacement reaction series "hypersthene→cummingtonitic amphibole→common hornblende,, in these basic xenoliths.

Optical properties of these minerals are given by Iwao as follows:

Specimen No. 34. 8. 3. 1. Locality :Mukuno, Ôshima

Hypersthene	Cummingtonite	Common hornblende
$\gamma=1.730$	$\alpha=1.658$	$\alpha=1.661$
$2V=54.5°$ negative	$\beta=1.672$	$\gamma=1.690$
X=colorless	$\gamma=1.683$	2V about X=68°–66°
Y=colorless	2V about X=81°–94°	
Z=colorless		X=yellow
	X=colorless	Y=greenish brown
	Y=colorless	Z=greenish brown
	Z=very pale green	

Biotite is hypidiomorphic, thick tabular with ragged margin.
Sporadically porphyroblastic biotite which is idiomorphic, thick tabular and occasionally poikilitic is developed. Axial color is light yellow to brown.

Quartz occurs in a small amount as granular crystals.

Granitization of Basic Rocks

Koide reported that basic rocks in the Dando district suffered granitization resulting in biotite granite through various intermediate rock types. Recently Ogura (1958) studied on the granitization of basic rocks in the Gosaisho-Takanuki district, southern Abukuma Plateau, where the basic rocks are subjected to granitization to various degrees. Iwao (1940) mentioned that basic rocks of the Yanai district were assimilated by the granite magma, and converted into quartz dioritic rocks. The plagioclase-quartz-biotite rock in which biotite predominates seems to be the relict of the pelitic banded gneiss which suffered granitization. The granitization of amphibolite and metadiabase will be described in the followig paragraphs.

The mode of occurrence of granitized rocks is very variable owing to the difference in original rock and metamorphism effected by the enclosing granodiorite (plata 19-3, 4, 5).

As the result of granitization the basic rocks, amphibolite and metadiabase, grade through variable stages into final products, which have been described in the foregoing pages as the hybrid rock facies of the Gamano granodiorite. As the petrogaphy of the basic rocks and the hybrid rocks have already been described, the transitional facies of the granitization will be mentioned here. Although it is difficult to distinguish various manners of granitization because of the variation of original rocks and physico-chemical conditions, the granitization series can be divided into the following types according to the field occurrences.

1) Network veins (trondhjemite). Numerous massive or irregular-shaped metadiabase occur on various scales within the Gamano gneissic granodiorite in the northwestern part of Ōshima Island. Most of them are accompanied by network veins of trondhjemitic composition (plate 19-4). The network veins usually have a well defined outline and are about several centimeters wide. Narrow biotite-rich zones sometimes fringe the inclusions adjacent to the network veins. There is no evidence to verify that the network veins are derived directly from the country rocks. It seems that these replacement veins have been formed by fracturing accompanied by progressive replacement, and thus they must be distinguished from igneous veins which have resulted from the magmatic injection into fissures. Aplitic veins derived directly from the host gneissic granodiorite cut the basic rocks.

These network veins are coarse-grained and leucocratic. They consist cf plagioclase, hornblende, quartz, and a small amount of biotite. Mineral composition is given in table 3. The texture of the veins is granoblastic and inequigranular. The contact between the amphibolite and the coarse-grained veins appears sharp in thin section. It is observed that the veins markedly differ in texture from the surrounding amphibolite.

Plagioclase is idiomorphic or hypidiomorphic, varying in grain size between 0.5 and 10 millimeters. Plagioclase ranges from An=38 to An=42 (An=40 on the average), being more sodic than that of the amphibolite (An=48~50) and more calcic than that of the Gamano mass (An=30~34). Large crystals are sericitized and sometimes replaced with calcite veinlets. Plagioclase has or has not polysynthetic twinning after the albite law, sometimes associated with the pericline twinning. The carlsbad twinning is rare. It is corroded in part by quartz, and no zonal structure is seen. Hornblende forms hypidiomorphic, short prisms of about 5 millimeters in length. Sometimes it is ragged in shape with sieve texture. Partly it is altered to chlorite. Optical properties are as follows: X=light greenish yellow, Y=greenish brown, Z= greenish-brown, $\alpha=1.650$, and $\gamma=1.673$. 2V about X=94°, $c \wedge Z=19°$. Colorless cummingtonitic amphibole occurs associated with hornblende as described in detail by IWAO (1940). Quartz is clear and fills interstices between other minerals. Sometimes it corrodes plagioclase and hornblende. Biotite occurs as thick tabular crystals which are often altered to chlorite. The pleochroism is X=pale yellow, Y≒Z=dark brown. $\gamma=1.658$.

Zircon, apatite and iron ores occur as accessory minerals.

2) Another evidence is seen at Ihoki, Hikari City, and on the coast of Migama, Oshima. Amphibolite masses, irregular or lenticular, about several meters wide, enclosed within gneissic granodiorites with distinct contact, contain many lenticular, medium-grained quartz diorite patches, which in part also grade into coarse-grained granodioritic patches. The boundaries of each rock facies are usually well defined.

Both amphibolites and lenticular medium-grained patches exhibit the lineation which is due to preferred orientation of mafic minerals. The trend of the lineation of granitization products is parallel to that of the host. The rocks are fine- to medium -grained, more leucoratic than the basic rocks, and have a gneissic appearance. They consist of plagioclase, quartz, biotite, and rarely of hornblende. The mineral composition is given in table 3. The texture is inequigranular and gneissic owing to the preferred orientation of biotite and quartz.

Plagioclase (An=36~42) is hypidiomorphic, prismatic or lath-shaped, mostly less than 4.0 millimeters long. Twinning after the albite law is common, and rarely after the carlsbad law. Large turbid crystals are often corroded by quartz, and normally zoned with calcic core. Quartz is lenticular or irregular in shape. It shows undulatory extinction. Biotite is hypidiomorphic-tabular with ragged edges. Trains of biotite flakes show preferred orientation. It is sometimes chloritized. The pleochroism is X=light yellowish-brown, Y=yellowish-brown, and Z=brown. Hornblende rarely occurs as hypidiomorphic crystals. Hornblende of the original amphibolite may have been converted to biotite as the result of granitization. As accessory minerals, zircon, apatite, iron ores and allanite are common.

3) Lastly, amphibolites and metadiabases gradually change into dioritic or tonalitic rocks. These features are most common and frequently observed in the basic rocks at Jônan and along the coast from Komatsu to Mukuno. At Jônan fine-grained amphibolite, which forms a large mass about one kilometer wide, grades into gneissic quartz diorite with the increase in grain size and quartzo-feldspathic minerals, that showing the series amphibolite→medium-grained gneissic quartz diorite→coarse grained granodiorite (plate 19-5). On the southern coast of Mukuno metadiabases which are irregular in shape changes gradually into medium-grained quartz dioritic rocks with intervening migmatitic facies between them. The rock is highy heterogeneus in grain size and color index. It exhibits a gneissose appearance owing to the alternation of mafic and quartzo-feldspathic layers. It consists of plagioclase, quartz, biotite and variable amounts of potash-feldspar and hornblende. The mineral composition is given in table 3. As accessory minerals sphene, apatite, zircon and opaque minerals are common.

Plagioclase is hypidiomorphic, varying in grain size. The composition is usually andesine, ranging between An=34 and An=40, approximately coinciding with that of the surrounding Gamano gneissic granodiorite. The albite and albite-pericline twins are common, and the carlsbad twin is rare. Large crystals have often suffered sericitization in the core, surrounded by more albitic rim. Quartz is irregular and interstitial. It sometimes grows into large pools consisting of several grains. Potash-feldspar, commonly orthoclase without microcline structure or perthitic intergrowth, fills the interstices between other minerals. Biotite is hypidiomorphic forming thick tabular crystals which tend to protrude into the surrounding plagioclase crystals. The pleochroism is: X=brownish yellow, and Y≒Z=dark greenish brown. The refractive indices of 5 specimens range from $\gamma=1.654$ to $\gamma=1.660$. Hornblende is hypidiomorphic or irregular in shape and sometimes poikilitic. It sometimes includes rounded grains of plagioclase and quartz. The pleochroism is: X=light yellow, Y=brownish-green, and Z=green. $\alpha=1.641$, and $\gamma=1.670$. 2V about X=70°. $c \wedge Z=18°$.

Younger Granodiorites

Tôwa Granodiorite

The Tôwa granodiorite is exposed in Tôwa Town located in the eastern part of

Ôshima Island, apparently extending eastward to the island swarm and Takanawa Peninsula, Ehime Prefecture. Granodioritic rocks of the Tôwa type may probably be the most widespread in the Ryôke zone on the scale of batholithic dimensions. From the lithological point of view, the Tôwa granodiorite may correspond to the Mitsuhashi granite after KOIDE, which is a younger intrusive body in the Dando district, Aichi Prefecture.

The Tôwa granodiorite varies petrographically ranging from granodiorite to adamellite. The granodiorite is exposed in the western area where it makes contact with the Gamano granodiorite, and the rock becomes gradually adamellitic toward the east. In the mapped area the granodiorite occupies greater portion while the adamellite is developed in the southeastern part of the region. There are no exposures presenting the contact relation between the Gamano mass and the Tôwa mass. The mineral composition is given in table 2. The proportion of constituent minerals varies as follows according to the change in facies (in volume percentage): plagioclase 30~50, quartz 20~40, potash-feldspar 5~40, mafic minerals (biotite, hornblende) 5~10.

Aplite and pegmatite are sometimes found as dikes or veins usually less than 2 meters wide, traversing the granodiorite. They are generally well observed on the coast from Morino to Kônoura. Basic xenoliths are sporadically found. Most of them conform in strike and dip to the structure of the host, and their shape is usually lens-like or flat ellipsoid measuring from 20 to 50 centimeters in length, and rarely thin layers. At Ôsaki is found a relatively large basic xenolith, which forms a tonalitic contamination facies with the granodiorite. The Ryôke metasediments are not found anywhere within the Tôwa granodiorite.

Granodiorite: Megascopically the rock is coarse-grained (plate 17-4) and characterized by a weak planar structure. The color-index of the rock is neutral in the west, but tends to become leucocratic toward the east. Locally the rock is porphyritic owing to the development of feldspar megacrysts which attain to 2.0 centimeters in length.

The rock is mainly composed of plagioclase, quartz and subordinate potash-feldspar and biotite (plate 19-4). Hornblende generally occurs in a small amount. The texture is granitic, obviously showing a magmatic origin. Even when the texture is porphyritic, feldspar megacrysts are uniformly distributed throughout the rock. In the porphyritic variety the rock consists of abundant potash-feldspar megacrysts scattered in a coarse-grained matrix composed of plagioclase, quartz and biotite. The megacrysts attain 2 centimeters in length and 1 centimeter in width.

Plagioclase (An=28~34) is idiomorphic to hypidiomorphic. Megacrysts of plagioclase show sometimes normal-zonal structure with turbid, relatively calcic cores. Minor crystals are fresh and slightly rounded. Multiple albite twinning is found, occasionally combined with the carlsbad twinning. Sometimes pericline lamellae occur.

Quartz forms frequently large pools, but small crystals are also found with irregular shape.

Orthoclase usually fills interstices between quartz and plagioclase. Phenoblastic crystal is idiomorphic, showing microcline structure. In rare cases, myrmekitic intergrowth occurs around the border of potash feldspar phenoblasts.

Biotite forms thick and tabular crystals with ragged edge. It tends to scatter and is often intergrown with hornblende. The pleochroism is: X = light brown, Y = yellowish-brown, $\gamma = 1.660 \pm 0.002$ (average of 3 samples).

Hornblende is hypidiomorphic, often showing poikilitic texture. The pleochroism is: X = light brown, Y = brownish-green, and Z = bluish-green. $\alpha = 1.658$, and $\gamma = 1.675$. 2V about Z = 80°. $c \wedge Z = 20°$.

Zircon, apatite, allanite, and iron ores are found as common accessory minerals.

Adamellite: Megascopically the rock is coarse-grained, generally leucocratic and locally somewhat porphyritic, showing planar structure and linear orientation of mafic minerals. Adamellite differs from granodiorite chiefly in containing much amount of potash-feldspar. Potash-feldspar is as large as plagioclase. Biotite is most abundant as main mafic constituent, followed by hornblende. The texture is hypidiomorphic, granular, and somewhat porphyritic.

Plagioclase is idiomorphic to hypidiomorphic. It is oligoclase rather than andesine in composition. Both the albite and the carlsbad twinning are common. Sometimes glomeroporphyritic intergrowth of plagioclase crystals with markedalbite twinning is developed. Some crystals are zoned with albitic, fresh rims and somewhat more calcic, turbed cores.

Potash-feldspar occurs in varying amount. It is micrcline, occurring as roughly hypidiomorphic and irregular large grains in the matrix. Perthitic intergrowth is not present; microcline structure is common. The carlsbad twinning is often present. Large crystals frequently include at random small, rounded grains of quartz, plagioclase and biotite. Plagioclase is rarely replaced poikilitically by microcline.

Quartz forms allotriomorphic grains, occupying irregular interspaces. In a more granitic facies, quartz shows occasionally undulatory extinction and cataclastic texture.

Biotite forms hypidiomorphic, thick-tabular crystals. It occurs as clots or scattering. It is pleochroic with X = reddish brown, Y = yellow, and Z = yellowish brown. $\gamma = 1.658 \pm 0.002$ (average of 3 samples).

Hornblende is hypidiomorphic, prismatic and often poikilitic. It forms usually mafic clots with biotite. The optical properties are almost similar to those of hornblende in the granodiorite facies.

Muscovite, apatite, zircon, and opaque ore are normal accessories.

Kibe Granite

The Kibe granite, which is exposed in an area of approximately 15 square kilometers, occupies the notheastern part of the area. Although there are no exposures indicating geological relationship between the Kibe granite and the Gamano granodiorite, the Kibe mass represents geologically as well as petrographically a distinct unit in the Ryôke zone of the district. The northern extreme of the mass has not been ascertained. Type rock of the Kibe granite is exposed along the Yû River between Kibe, Hizumi and Sadakuni, Yû Town.

Megascopically the rock is coarse-grained, and porphyritic due to the development of microcline megacrysts (plate 17-5). Locally the rock shows a faint planar structure by the arrangement of biotite flakes. Occasionally are contained a few rounded or lens-like basic xenoliths which attain scores of centimeters in length. Large microcline crystals which give the rock a distinct porphyritic appearance, are either aligned parallel to the general foliation of the rock or dispersed at random. The Ryôke metasediments are not found within this granite.

The texture is somewhat porphyritic (plate 21-5). The rock consists mainly of plagioclase, quartz, and potash-feldspar with subordinate biotite. The mineral composition is shown in table 2.

Plagioclase is hypidiomorphic, being smaller than microcline in grain-size. Twinning is usually after the albite law, although the pericline and the carlsbad twinnings are also occasionally observed. It has often suffered sericitization. Zonal structure is rare. Some of the plagioclase crystals are enclosed by microcline and quartz.

Potash-feldspar is represented by microcline, occurring as roughly idiomorphic crystals which attain to 2 centimeters in length. Sometimes it occurs as irregular grains in the matrix. All transitions from allotriomorphic interstitial microcline to large idiomorphic one are found. Perthitic intergrowth is not observed. Microcline megacrysts often contain many fine, unoriented grains of quartz and plagioclase.

Quartz is allotriomorphic, forming rather large crystals.

Biotite is thick and tabular, occurring as clots. Biotite includes commonly small grains of apatite and zircon which is surrounded by pleochroic haloes. The pleochroism of biotite is: X=yellow, Y=reddish brown, and Z=brown. $\gamma=1.658\pm0.002$ (average of 3 samples).

Zircon, muscovite, apatite, and opaque minerals are common accessories.

Murotsu Granite

The Murotsu granite occupies the area about 3 kilometers across at the top of the Kumage Peninsula. It also occurs in the eastern part of Nagashima Island. The greater portion of this mass is overlain by the Pliocene andesite. Therefore, the contact relation between this granite and other granodiorites cannot be determined in the mapped area. However, the older gneissic granodiorites and the siliceous banded gneiss are found to be intruded discordantly by the Murotsu granite in the eastern part of Nagashima. On the coast of Murotsu this granite discordantly cuts the banded gneisses. Xenoliths of either metasediments or basic rocks are not found within this mass.

The rock considerably differs from other granodiorites mentioned above in that it is homogeneous two-mica granite lacking always in gneissosity. Megascopically the rock is medium-grained, leucoratic, and homogeneous (plate 17-6). The rock is mainly composed of plagioclase, potash-feldspar, quartz, and subordinate biotite and muscovite. Its mineral composition is shown in table 2. In thin section the rock exhibits a hypidiomorphic, granular, and somewhat porphyritic texture (plate 21-6).

Plagioclase ($An=28\sim34$) tends to form idiomorphic crystals. Large crystals are often zoned with albitic rims grading into somewhat more calcic, sericitized cores. Twins after the albite, carlsbad and pericline laws are common. Large phenocrystic grains include rounded quartz, plagioclase, biotite, and muscovite.

Potash-feldspar is either represented by microcline of large allotriomorphic crystal, or by orthoclase which fills interspaces between other minerals. The large phenocrystic grains frequently include rounded quartz, plagioclase, and muscovite. Myrmekite seldom occurs.

Quartz forms allotriomorphic crystals with intricate outlines. It is to be noticed that quartz exhibits in places cataclastic texture and strikingly undulatory extinction.

Biotite occurs as thick tabular crystals. The pleochroism is: X=yellow, Y=reddish brown, and Z=brown. $\gamma=1.658\pm0.002$.

Muscovite forms thin plates. It tends to form aggregates with biotite.

Zircon, apatite, and iron ores are common accessory minerals.

Fine-Grained Granodiorite

The younger granodiorites were followed by the injection of many fine-grained granodiorites in many parts of the region. They occur as dikes or irregular, sheet-like masses traversing either the older granodiorites and the associated banded gneisses or the younger granodiorites. Accordingly, these fine-grained granodiorites are to be inferred as representing the latest intrusive in the phase of the Ryôké igneous activity of the region. For the sake of descriptive convenience, they are divided after their modes of occurrence into two types, Type I and Type II. Brief petrographical descriptions of these rock types will be given in the following paragraphs.

Type I: Rocks belonging to Type I occur as sheets, lens-like or massive bodies several hundred meters across. They are exposed as irregular masses, being distributed throughout the region, viz. at Ihonoshô, Chausuyama, Fujinoki, and in the eastern part of Ôshima-gun. The boundaries between the country rocks and the fine-grained granites are well defined in some places, showing sharp contact and faint flow structure in the fine-grained granites parallel to the boundary surface.

Megascopically the rock is fine-grained, leucocratic, and homogeneous. Near the contact with the country rocks it has often chilled margin which is more or less aplitic with flow structure. The rock is mainly composed of plagioclase, quartz, potash-feldspar, and small amounts of biotite and muscovite. The average mineral composition is given in table 2. In thin section, the rock usually exhibits hypidiomorphic, granular texture (plate 21-7), and somewhat porphyritic in the masses distributed in Ôshima Gun.

Plagioclase forms idiomorphic, large crystals, often turbid and sericitized in core. Twins after the albite and carlsbad laws is common. Potash-feldspar occurs as allotriomorphic crystals filling interspaces between other minerals. No microcline and perthitic structures are observed. Quartz forms granular or allotriomorphic crystals. Both biotite and muscovite occur in small amounts. The pleochroism of biotite is: X=light brown, Y=dark brown, and Z=reddish brown. Occasionally muscovite replaces plagioclase. Zircon, apatite and iron ores are common accessories.

Type II: Rocks of Type II occur as dikes of from several to scores of meters in width. Along the coast from Mukuno to Komatsu, Ôshima-gun, several dikes with the general trend of N 20° E in strike and 70° N in dip are developed. The boundaries between the country rocks and the dikes are sharply defined. Near the contact they usually exhibit aplitic or pegmatitic margin. Megascopically the rocks are fine-grained, leucocratic, and homogeneous.. In thin section the rock is mainly composed of plagicolase, quartz, potash-feldspar, and small amounts of biotite and muscovite. The average mineral composition is given in table 2. The rock exhibits hypidiomorphic texture, which varies from granular to porphyritic ones according to the development of plagioclase megacrysts.

Large crystals of plagioclase, which attain 5 millimeters in length, exhibit oscillatory zoning with calcic cores which grade into more albitic rims. The cores are sericitized and turbid, while the albitic rims are clear. Potash-feldspar is allotriomorphic, occupying the interspaces. Its large crystals occasionally include small plagioclase and quartz. Neither microcline nor perthitic structures occur. Quartz is allotriomorphic. Both biotite and muscovite occur in small amounts. The pleochroism of biotite is: X=light yellow, Y=brown, and Z=dark brown. As accessory minerals zircon, apatite, and iron ores are common.

IV. MESOSCOPIC AND MACROSCOPIC STRUCTURES

The structural analysis was made on the basis of the mapping on the scale of 1: 25,000 and a large amount of measurements of structural elements such as foliation plane and linear structure recorded on the field. The region is partly unsuitable for structural analysis owing to the scarcity of outcrops. There are, however, some extensive exposures on the coasts and in the deeply dessected valleys, which greatly favored the structural study. The geologic map shows the trend of foliation of the banded gneisses and the granodiorites. For the purposes of structural analysis the region in question was divided into six subareas. Data of the field information were plotted on the lower hemisphere of equal-area-projection after the method as has been developed by WEISS, McINTYRE, RAMSAY, and so on. This method makes it possible not only to obtain a clear picture of the orientation of various structural elements in each subarea, but also to clarify their variations from subarea to subarea. Fig. 8 (pl. 14) was prepared to show the relationship between the foliation and the lineation of the banded gneisses and the granodiorites in each subarea.

STRUCTURE OF THE BANDED GNEISSES

Foliation: In the banded gneisses the foliation, the compositional banding, is well developed, giving the rock the gneissic appearance composed of alternating bands of meranocratic and leucocratic compositions.

The compositional banding of siliceous banded gneiss which occupies greater portion of the region in question is of 1 to a few centimeters in width, that corresponding to the banding of banded chert in the northern non-metamorphic Palaeozoic formation from which the siliceous banded gneiss has been derived. The foliation plane coincides with the plane of preferred orientation either of platy minerals, such as biotite, or of mineral grains such as quartz, namely, the schistosity plane in the sense of A. HARKER (1932). The foliation plane can be interpreted in the region in question as inheriting the bedding or the lamination plane of the original sediments, accentuated by the metamorphic differentiation. Therefore, the foliation coincides with the bedding schistosity.

The foliation of the pelitic banded gneiss corresponds to the compositional banding (S_1) consisting of alternating quartzo-feldspathic and micaceous layers of several millimeters in width. Some rocks are markedly fissile along the foliation plane, which coincides with the schistosity plane. As the result of his investigation of the Ryôké metamorphics of the Dando district, H. KOIDE (1958) has believed this banding to be a segregation product originating from the surrounding metamorphics under the physico-chemical environments caused by the alkali-alumina emanation. According to the present author, however, the foliation of pelitic banded gneisses, particularly that of more strongly deformed rocks, represents a structure mechanically produced by differential movements along the bedding or lamination plane.

The rocks within the region are characterized by the presence of single megascopic

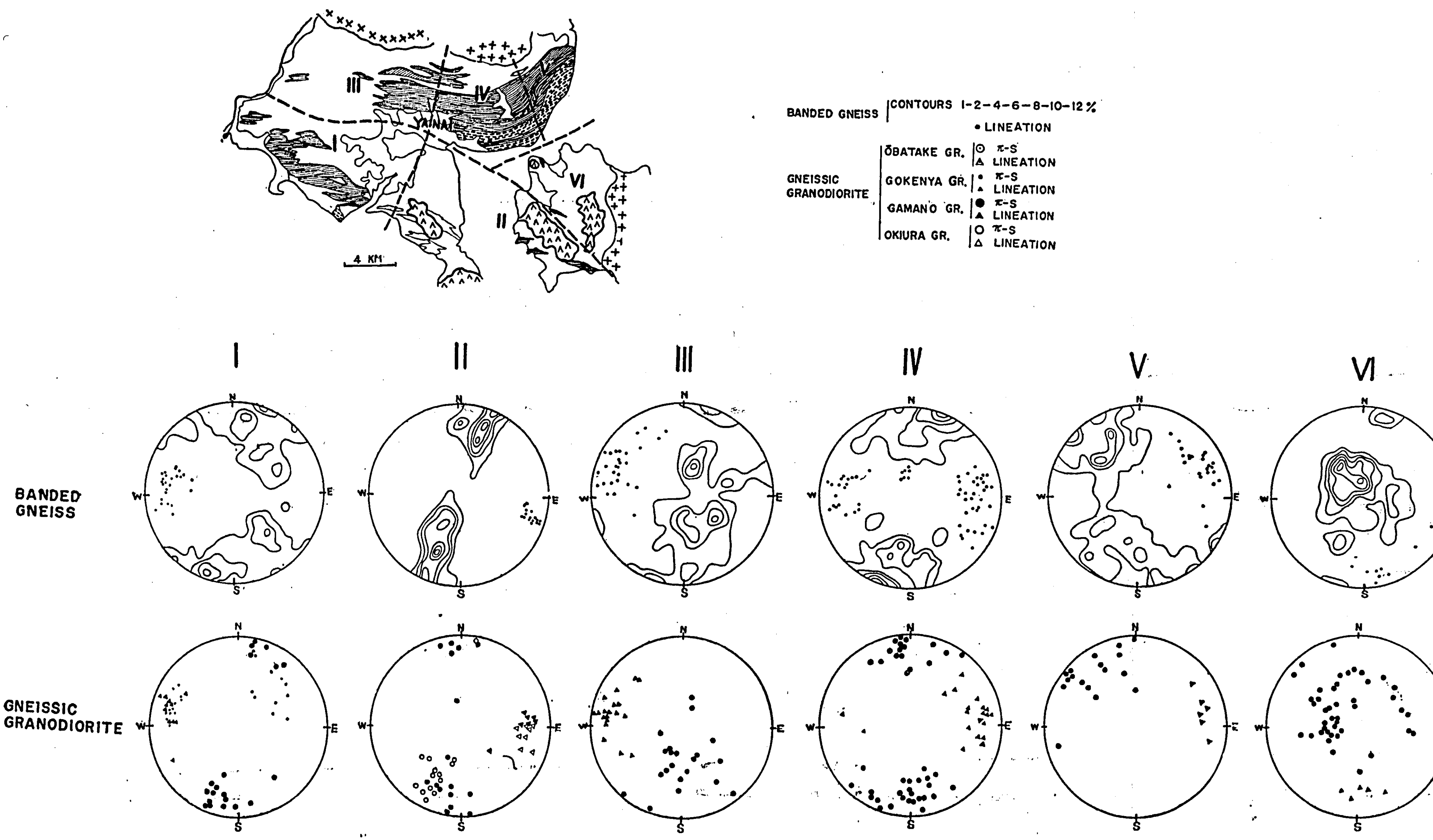

FIG. 8. Foliation planes and lineations of banded gneisses and gneissic granodiorites.

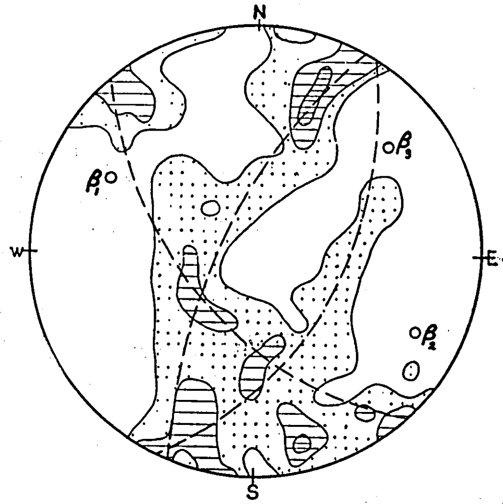

FIG. 9. Collective diagram, in which are plotted 700 poles (πS_1) of foliation planes measured in the whole area.
Contours: 3-2-1 %

s-plane, except for one sample of semipelitic banded gneiss at Ôkubo, Ôbatake Town, which shows fracture cleavage (S_2) oblique to the bedding schistosity (S_1). In siliceous banded gneisses, no megascopic s-plane which traverses S_1 is not observed.

The trend and distribution of the banded gneisses are shown in the geological map. In the northern half of the map is shown a remarkable arcuation in the trend of the banded gneisses, the trend changing N.70° W.∼E./W.∼N.E. from W. to N.E. along the coast from Yanai to Yû. This arcuation is represented by the variation in trend of the foliation and lineation between subareas III, IV, and V in fig. 8. In the southern half of the region, where banded gneisses are sporadically distributed, the strike is predominantly N.70° E. and the dip is mostly toward the north, as shown in diagrams for subareas I, II, and VI in fig. 8. These relations are expressed in the collective π-diagram for foliation planes of the whole region by the presence of several great-circle girdles (fig. 9).

Although the foliation plane of banded gneisses has locally variable dip and strike, poles of the foliation plane (πS_1) plotted on the diagram tend to lie in a great-circle girdle, which defines the axis β, the tautozonal axis of πS_1.

In Ôshima Gun, in spite of their discontinuous distribution of the banded gneisses, their stratigraphic continuation is well traceable. Both toward the west and the east in the direction of strike, the banded gneisses gradually pinch out or become isolated small bodies within gneissic granodiorites. These small layers or xenolith-like masses of banded gneiss are not distributed at random, but they are arranged so as to keep the stratigraphical horizon of banded gneisses.

Fold: The bedding foliation surface is generally folded on various scales with gently plunging axes (B). These folds are believed to have been formed syngenetically

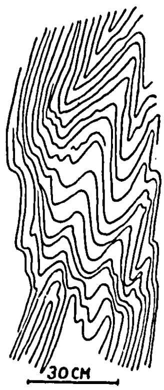

FIG. 10. A section of folded siliceous banded gneiss, Tana. ⊥ *b*.

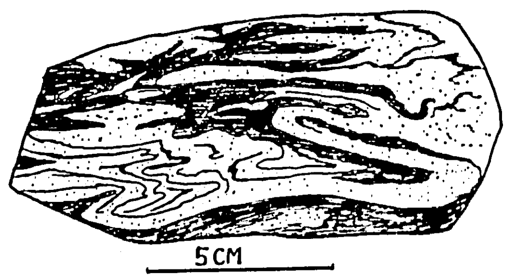

FIG. 11. A section of fold in pelitic banded gneiss, Saga. ⊥ *b*.

with the mechanical foliation. In most of the siliceous banded gneisses axial planes of adjacent folds generally show subparallel orientation as seen in fig. 10, dipping steeply. Locally, however, considerable variations are seen in the attitude of the axial plane. In places, where the bedding foliation surface is plain, its direction is parallel to that of the axial plane of folds. Many folds of the siliceous banded gneiss have no megascopically visible secondary foliation parallel to the axial plane.

In pelitic banded gneiss S_1 forms locally recumbent folds, as shown in fig. 11. The visible foliation of the rock represents most commonly a structure mechanically produced by differential movement along the bedding plane. Siliceous and psammitic thin layers within the pelitic banded gneiss are parallel or subparallel to the foliation, that showing the derivation of S_1 from the bedding, but, when carefully examined, the individual layers form discontinuous lenses, showing transposition structure (plate 16-1). Therefore, it must be inferred that, locally at least, rather strong shear movement has been occurred along the foliation surface of pelitic banded gneiss. On the contrary, such strong shear structure can not be found within siliceous bended gneiss, that suggesting the difference in material condition between pelitic and siliceous banded gneisses at the time of deformation.

In the central area (subarea IV), where the strike of banded gneiss is distinctly curved, the secondary fold or wavy structure of the foliation surface S_1 can be observed in places. The orientation of the axis of this type of fold is not consistent, but it is a type of down-dip-fold, generally plunging very steeply. There are, however, found no exposures showing the coexistence of the down-dip-fold with the moderately plunging *B*-fold.

Lineation: The lineation is well developed in almost all rock types, especially most remarkable in the siliceous banded gneiss and the pelitic banded gneiss. The following types have been recognized megascopically, and when occurring together in the same outcrop they are always parallel to each other:

1. Axis of microfold. Most of microfolds are accompanied by folds on larger

scales. The axial trend of these microfolds is constant, coinciding with those of lineations of other types. These lineations define the fabric axis *b*, corresponding to the *B*-lineation defined by SANDER (1950).

2. Parallel orientation of minerals. Parallel elongation of minerals such as biotite and quartz which are developed on the foliation planes well defines the lineation.

3. Striation and minute corrugation on the foliation plane. These are also parallel to the fold axis.

Among these types of lineation, the trend of the axes of microfold and the parallel orientation of minerals on the foliation surface have been measured and plotted.

Some of the lineations are seen to have been formed by the intersection of bedding foliation with an axial-plane-foliation (a shear plane), but no other types of lineation were found to have been formed by the intersection of the other sets of *s*-surfaces.

The lineations in each subarea are shown in πS diagrams of fig. 8 (pl. 14). As seen in the diagrams, the lineation is generally subparallel to the trend of the banded gneisses, *i. e.*, in the northern half where the banded gneisses make an arcuation, the trend of lineation changes N.60° W.~E./W.~N. 45°E. from the west to the east, while in the southern half it is consistently N.70°W.~N.80° W., except for a few localities. Everywhere in the western part (subareas I, and III) the lineation plunges westward, while in the central part (subarea IV), where the banded gneisses are bent, the plunge of lineation is more or less variable, and in the eastern part (subareas V, and VI) it generally plunges to the east or to the northeast. That is to say, by passing the zone extending from Kurokui, Yanai City to Tana, Saga, from the west to the east, the plunge of lineation changes its direction, that suggesting an arch structure of anticlinal nature.

Fig. 12 shows the projection of 200 lineations in the whole region. In the diagram are seen marked three maxima, B_1, B_2, and B_3, which coincide practically with β-

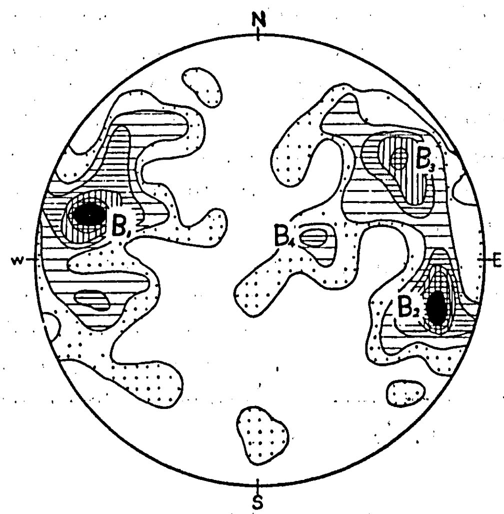

FIG. 12. 200 lineations measured in the whole area.
Contours: 6-5-4-3-2-1 %

maxima, β_1, β_2, β_3 in the πS_1 diagram (fig. 8).

β-diagram: In recent years the study of the regional structural geometry by making use of the β-diagram of Sander (1948) has been greatly developed by many investigators such as WEISS and MCINTYRE (1957, 1954) in southern California, Scottish Highlands and other regions in order to clarify the homogeneity of structure and the overprinting of deformation phases.

In the region under consideration, 19 β-diagrams were prepared from respective subareas in order to establish the scope of the homogeneity and to clarify the characters of deformation of the banded gneisses. Each diagram consists of 15 to 25 measurements of foliation surfaces; all the points of intersection of foliation surfaces were plotted and contoured in each diagram. The coutours are drawn every 5 per cent per 1 per cent area. The results are shown in fig. 13 (pl. 15).

Fig. 13 reveals that there is a considerable variation in the trend and plunge of β in different subareas. It has already been mentioned that the change in trend of the foliation and lineation from the west to the east of the region represents the most remarkable structural feature. The change in trend of β-maximum in fig. 13 from the west to the east seems generally to correspond to the change with respect to the foliation and lineation above mentioned, but in the central part of the region there cannot be found no correspondence between them. Subareas 4, 6, 15, 16, and 17 have distinct single maxima without any significant dispersion, which coincide with the fold axis (B) in each subarea. The diagrams of subareas 3, 5, 8, 12, 14, and 18 show β-maxima having the tendency to disperse along a great circle, because in these subareas the foliation surfaces are only gently folded with no definable fold axes.

The respective β-maximum plunges generally at low angles, coinciding with the lineation of respective subarea. In a few subareas irregular patterns are caused by local disturbances (subareas 1 and 7), but as a whole folds with the axis β//B occur throughout the region. In these types of macroscopic structural geometry no evidences are available to infer the overprinting of folds of different deformation phase.

It should be noted that the diagrms of subareas 11 and 13, consisting chiefly of unfolded foliation of siliceous banded gneiss, show steeply dipping β-maxima with tendencies to disperse along great circles. In these cases the β-maximum does not coincide with the regional B or B lineation. In subareas 12 and 14 high angle submaxima can be seen. It is an important fact that the β-maximum or β-submaximum of down-dip nature occurs in the subareas where the regional trend is bent from W. N. W. to N.E. The developement of the β-maximum or submaximum plunging steeply to N. W. or N. E. can be attributed to the bending or warping on a regional scale which occurred during or after the B-folding. The submaximum B_4 in fig. 12 corresponds to these down-dip β.

STRUCTURE OF GRANODIORITES

It has already been noticed by IWAO (1938), KOJIMA and the writer (1953) that

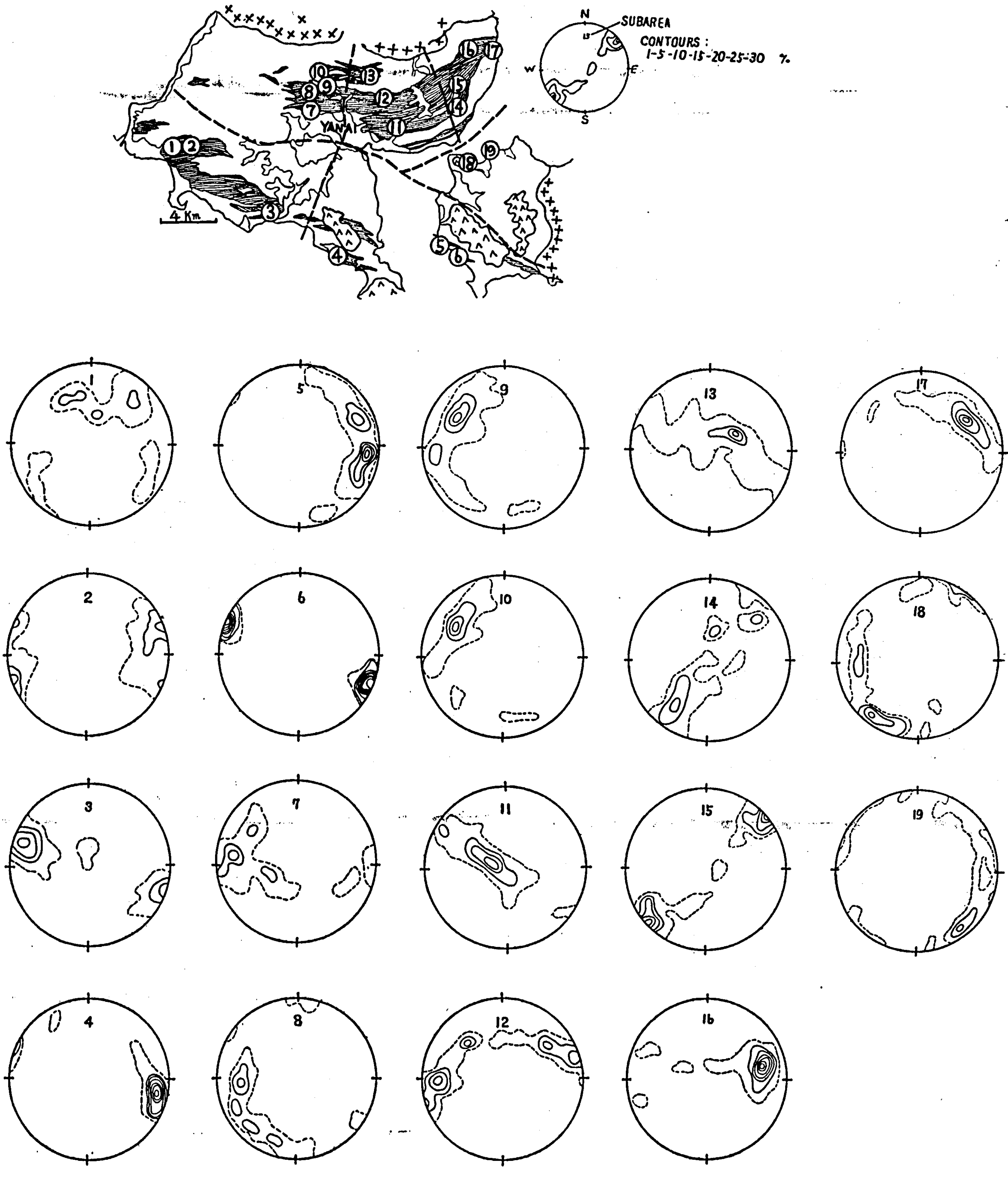

Fig. 13. β-diagrams.

some granodiorites of the Ryôké zone are characterized by the presence of gneissosity which is conformable to the structure of the metamorphic rocks. On the basis of their extensive geological survey, KOJIMA and the writer emphasized that these granodiorites are harmonic and subconcordant to the banded gneisses.

Characteristics and geometrical relations with respect to such structural elements as foliation, lineation, inclusion and schlieren of each mass of granodiorite will be described in the following.

Older Granodiorite

Foliation: The foliation is represented by the banded structure, the alternation of parallel aggregates of biotite flakes and quartzo-feldspathic layers. The banded structure is generally regular in fine-grained rocks, while it becomes irregular as the grain-size becomes coarser, owing to the pinch and swell of leucocratic layers. In general the foliation surface is planar but locally it is wavy or folded, especially near the contact with the banded gneisses and in a migmatitic facies. No other types of *s*-surface are observed within the gneissic granodiorites.

Lineation: Visible lineation of the gneissic granodiorites is defined by the parallel elongation of mineral grains such as biotite and hornblende. In the rocks with distinct foliation, the largest face of feldspar crystal tends to be parallel to the foliation, and the arrangement of longer diameter of crystals defines the lineation. As will be described below, basic inclusions often show linear structure.

Inclusion and schlieren: As stated in the preceding chapter, numerous inclusions of banded gneisses and basic rocks, which are shaped as lenses or films, are found throughout the whole area of the older granodiorites.

Thin layers of banded gneisses, from several to more than ten meters in width, can be traced in the gneissic granodiorites, that representing the continuation of the original stratigraphical horizon. Structural elements such as foliation and lineation of these remnants are always harmonic to those of the country rocks.

Whenever the basic inclusions are flattened and elongated, they are arranged with their longest axis parallel to the gneissosity of enclosing gneissic granodiorites. Not only the basic inclusions are oriented parallel to the gneissosity of the host rocks, but their lineations defined by the constituent minerals, such as hornblende, also shows parallel arrangement. The older granodiorites, except the Gokenya mass, have the schlieren or nebulitic structure which suggests the migmatization or granitization of banded gneisses. They show perfect concordance with the structure of the host rocks.

The structural features of each gneissic granodiorite are as follows.

The Ôbatake gneissic granodiorite: The foliation is distinct, suggesting the inheritance of the structure from banded gneisses. The foliation dips steeply and is parallel to the trend of the surrounding banded gneisses. The lineation is weakly developed in most exposure. In places only the lineation due to flaky biotite and prismatic hornblende is observed, and no foliation is found. The trend of the lineation is generally N.70°E.~N.60°E., plunging gently toward the east, in spite of a local anticlinal structure of the foliation at Nakayama. The fine-grained dark inclusions are generally platy and nearly parallel to the foliation. The nebulitic structure or schlieren of banded gneisses are observed in many places.

The Gokenya gneisssic granodiorite: The foliation is very distinct, being represented by the fine alternation of leucocratic and meranocratic layers of a few millimeters in width. The foliation is generally parallel, locally oblique, to the structure of the surrounding Gamano gneissic granodiorite and the siliceous banded gneisses. The foliation of the mass strikes N.30°∼50°W. and dips 30°∼50°S.W. Distinct lineation is defined by the intense elongation of biotite flakes and quartz grains. Although the foliatlon of the mass is subconcordant or disharmonious to the Gamano mass, the lineation is always concordant (fig. 8). The lineation of the.mass strikes N.60°W. and plunges 30°N.W.

The Gamano gneissic granodiorite: As this mass is most widely distributed throughout the whole region, its structural relationship with the banded gneisses is very interesting. In general the foliation is distinct, but in places no foliation is observed in spite of the preferred orientation of biotite flakes. In the western margin and the Ihonoshô district, the rock is massive lacking in foliation. Roughly speaking the foliation of the Gamano mass is concordant and harmonic to the trend of the siliceous banded gneisses. In the northwestern part of Ôshima Gun, where a local anticlinal structure with axis plunging toward the southwest is found (Migama), the diverging structure opened toward the east can be detected as a continuation from the mainland.

The Gamano gneissic granodiorite often exhibits an aplitic facies without foliation near the contact with the banded gneisses, but within a short distance it gradually comes to have a planar structure parallel to the structure of banded gneisses. Locally, where the Gamano mass cuts discordantly the banded gneiss, as seen in the Kandori Cape, the foliation of the granodiorite oblique to the boundary surface is parallel to the compositional banding of the banded gneiss (plate 19-1). At Munemitsu a folded structure which seems to be a relic structure due to the granitization of siliceous banded gneiss can be seen.

The lineation due to the weak preferred orientation of biotite clots and prismatic hornblende is observed in some places, but usually the lineation is not well developed.

Blocks of banded gneisses included within the migmatitic facies of the Gamano mass are oriented subparallel to the foliation of enclosing rocks and some are rotated, that suggesting the mobilization of the Gamano mass.

The Okiura gneissic granodiorite: An intense foliation is represented by fine banding due to parallel arrangement of biotite flakes and sometimes by alternating bands of different grain-size. The foliation always trends about N.70°W. and steeply dips N. like the banded gneiss. Distinct lineation is defined by the elongation of biotite flakes and quartz grains. As shown in the diagram of fig. 8, the lineation of the mass is concordant to those of the banded gneisses.

π of foliation planes and lineations of each gneissic granodiorites were plotted in Schmidt-nets and placed below those of the banded gneisses in fig. 8, in order to show

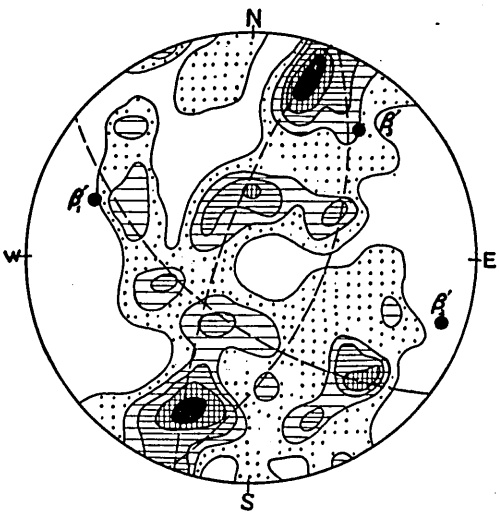

FIG. 14. Collective diagram, in which are plotted 105 poles (πS) of foliation planes of gneissic granodiorites measured in the whole area. Contours: 5-4-3-2-1 %.

the structural relationship between the banded gneisses and the gneissic granodiorites. These diagrams show quite clearly that the structural trend of the banded gneisses is conformable to those of the gneissic granodiorites. Fig. 14 is an equiareal projection of 105 poles of foliation surface of gneissic granodiorites in the whole region. The pattern of the diagram is very similar to that of the diagram for banded gneisses (fig. 9).

Younger Granodiorite

The planar structures due to the arrangement of mineral grains and aggregates of grains are developed in the Tôwa granodiorite and the Kibe granodiorite in many places. The structure does not result from the banding of mineral aggregates such as biotite flakes, but is defined by the statistical orientation of minerals. NUREKI (1958) has reported that the planar structure of this type should be distinguished from such structures as foliation or gneissosity, and that the planar structure of the younger granodiorites can be inferred to be the result of differential movement or magmatic flow of each mass. The orientation of mafic minerals such as biotite and hornblende shows a typical flow structure. The planar structure becomes more distinct as the parallelism of mineral grains becomes more complete. In places larger porphyritic crystals of feldspar tend to show parallel orientation.

Linear structure of the younger granodiorites is in places expressed by the directional orientation of elongated biotite flakes and hornblende prisms. In general, however, linear structure is weakly developed or lacking.

Sometimes fine-grained dark inclusions are found. They are always elongated or ovoidal in outline, and are arranged nearly parallel to the flow structure.

The Tôwa granodiorite: The planar structure is generally developed throughout the whole region. It trends N.20°∼50°E., N.30° to 40°E. on the average, and dips 30°∼50° toward S.E. Therefore, at the west margin where the Tôwa granodiorite comes in contact with the Gamano and Okiura gneissic granodiorites, the planar structure of the Tôwa granodiorite is parallel to that of the Gamano mass in the northern portion, but in the southern portion it gradually cuts the trend of the structures of the Gamano and the Okiura masses as their foliations change from N.E./S.W. to W.N.W./E.S.E. No contacts between the Tôwa mass and the older masses can be observed. Linear structure due to the directional orientation of hornblende prisms and elongated biotite flakes is observed in places. Throughout the whole region the Tôwa granodiorite neither makes contacts with the banded gneisses nor contains the latter as xenoliths. Fine-grained dark inclusions, ranging in maximum dimension from less than ten centimeters up to one meter, occur in the Tôwa granodiorite, arranged parallel to the flow structure.

The Kibe granite: The rock shows usually faint flow structure with the general strike of E.N.E. and the dip of 30°∼60°N., the trend being approximately parallel to that of the Gamano granodiorite. In some places fine-grained dark inclusions occur parallel to the flow structure, but no xenoliths of gneisses can be found.

The Murotsu granite: The mass is perfectly homogeneous and massive, exhibiting no internal directional structures. Granitized banded gneisses are discordantly intruded by the Murotsu granite.

Fine-grained granite: Massive bodies and dikes of fine-grained granites are distributed in the Gamano gneissic granodiorite and the Tôwa granodiorite masses, discordantly cutting the structures of host rocks. The rock is generally homogeneous, although flow structure is seen near the contact in some places.

V. PETROFABRIC ANALYSIS

GENERAL REMARKS

As stated in the preceding chapters, the granitization of banded gneisses gradually advances towards the south and the granitized banded gneisses pass into the gneissic granodiorites. For the purpose of fabric analysis, orientated specimens of typical samples in each metamorphic stage have been collected within the area under consideration. In order to complete the petrofabric analysis, careful observation and recording of all mesoscopic field data on the rocks to be studied are indispensable. The reference axes a, b and c were defined with regard to the mesoscopic fabric, *i.e.*, b is defined by the principal lineation, and the schistosity plane is taken tentatively as (ab) plane. Diagrams of quartz, biotite and plagioclase were prepared in the sections normal to the lineation (b) and the foliation. All diagrams are viewed from the east.

Quartz diagrams show the distribution of the optic axis, and mica diagrams represent that of the pole of the cleavage (001). All diagrams were projected on the lower hemisphere of equiareal projection. Fig. 15 shows the locality of samples and the fabric pattern of which will be described below.

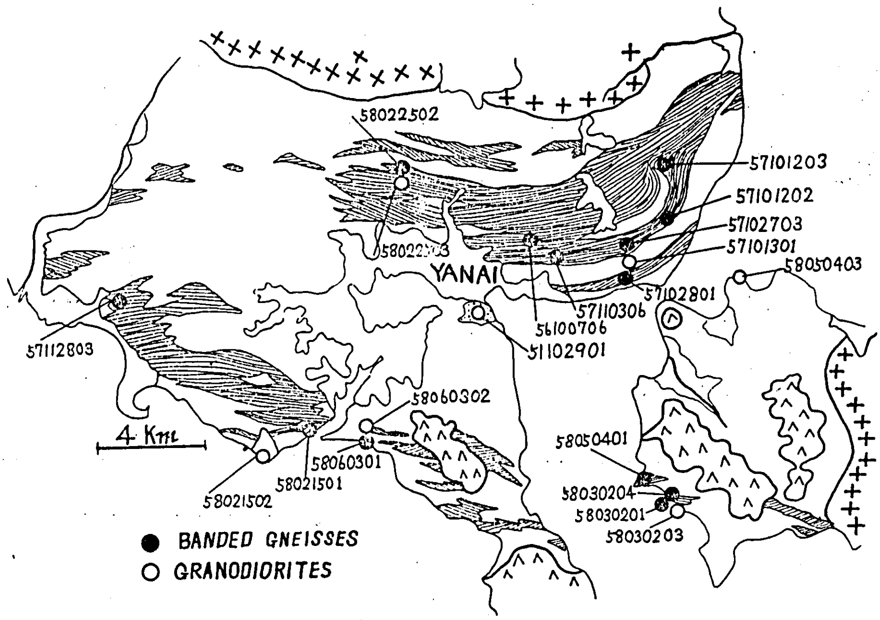

FIG. 15. The locality of analysed specimens.

SILICEOUS BANDED GNEISS

The siliceous banded gneiss proper is widely distributed, becoming thicker in the central part of the region in question. In the northern region the rock displays no effect of granitization. Four samples with distinct, unfolded plane foliation and one sample with folded foliation were measured.

Specimen 56100706

Locality: South of Mitsugadake, Yanai City.

The compositional banding (foliation in a narrow sense) are very distinct. The foliation surface is plane, but fine crincles define the lineation on the foliation surface. Other types of *s*-surface and lineation are not seen. The rock consists mostly of quartz with minor amounts of biotite and garnet. Quartz is rather coarse-grained (0.002∼1mm), equidimensional and equigranular, and large grains show undulatory extinction. Parallel flakes of biotite form layers.

400 c-axes of quartz were measured without selection of grains. The fabric diagram is shown in fig. 16. The c-axis of quartz is concentrated near the periphery, but the concentration of the maxima is not strong. The symmetry of the pattern is not definable. No trace of girdle about *b* or *a* is detectable.

Fig. 17 shows the orientation of 200 [001] of biotite flakes. Single strong maximum amounting to 10 percent coincides with the pole of the observed foliation surface. The diagram shows slight dispersion along (*ac*) plane.

Specimen 57101203

Locality: Mizunashi, Hizumi, Yanai City.

Petrographic characters of the rock are very similar to the one mentioned above.

500 c-axes of quartz were measured in (*ac*) section without selection of grains. The fabric diagram is shown in fig. 18. The pattern of the diagram shows no significant symmetry.

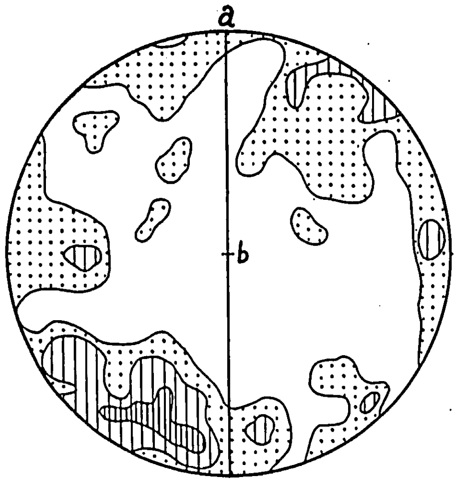

FIG. 16. 400 c-axes of quartz in siliceous banded gneiss from the south of Mitsugadake (Sp. 56100706).
Contours: 3-2-1 %.

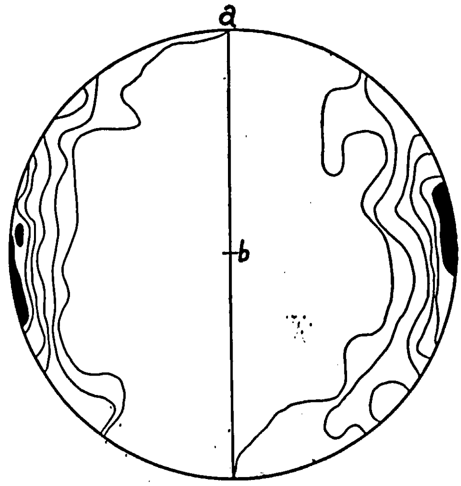

FIG. 17. 200 poles of biotite cleavage in siliceous banded gneiss from the south of Mitsugadake (Sp. 56100706).
Contours: 10-8-6-4-2-1 %.

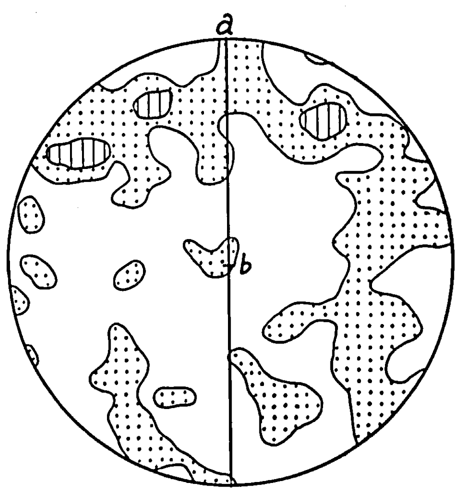

FIG. 18. 500 c-axes of quartz in siliceous banded gneiss from Mizunashi (Sp. 57101203).
Contours: 2-1 %, Max. 2.9%.

Specimen 57101202

Locality: Kannon Fall, Kôjiro, Ôbatake Town.

The schistosity and compositional banding are very distinct and plain. The lineation on the foliation surface is distinct due to the parallel orientation of biotite (L_1), accompanied by the subordinate wavy fold (L_2), of the foliation surface. The thin section for measurement was cut at the right angle to *a*. The rock consists chiefly of quartz and a small amount of biotite. The quartz grains are rather equigranular and equidimentional.

The fabric diagram of quartz, based on the measurement of 355 grains, is shown in fig. 19. The pattern

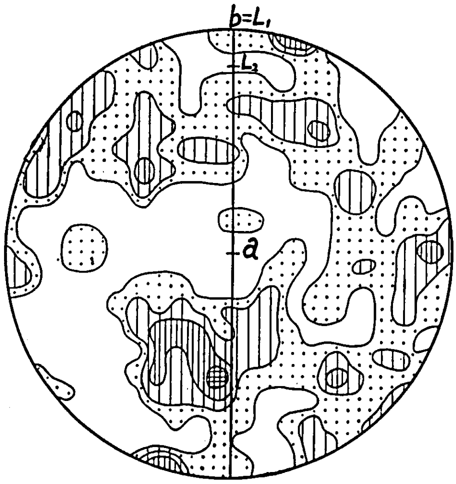

FIG. 19. 355 c-axes of quartz in siliceous banded gneiss from Kannon Fall (Sp. 57101202). Contours: 4-3-2-1%.

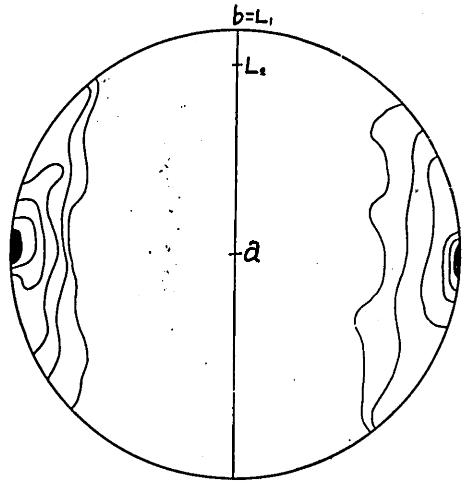

FIG. 20. 200 poles of biotite cleavage in siliceous banded gneiss from Kannon Fall (Sp. 57101202). Contours: 10-8-6-4-2-1%.

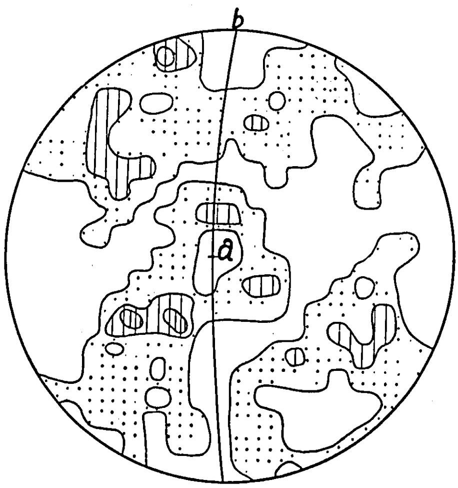

FIG. 21. 400 c-axes of quartz in siliceous banded gneiss from the north of Chausuyama (Sp. 57110306).
Contours: 3-2-1%, Max. 3.6%.

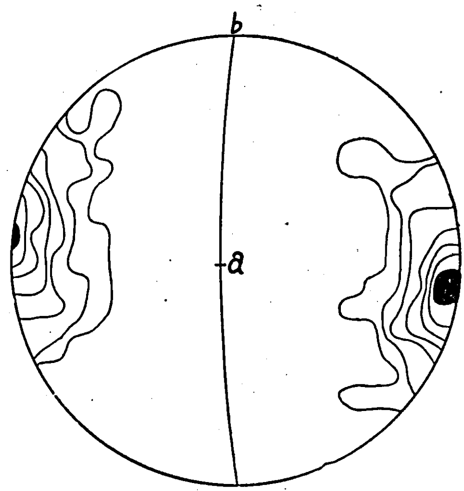

FIG. 22. 200 poles of biotite cleavage in siliceous banded gneiss from the north of Chausuyama (Sp. 57110306).
Contours: 12-10-8-6-4-2-1%, Max. 14%.

is rather irregular, and no significant symmetry is detectable, except a faint maximum referable to the position IV after SANDER and FAIRBAIRN.

The biotite diagram in fig. 20 was made from the measurement of 200 flakes without selection of grains. The preferred orientation of biotite flakes parallel to the megascopic schistosity is distinctly shown in the diagram.

Specimen 57110306

Locality: North of Chausuyama, Yanai City.

Megascopic structure of the rock is very similar to the samples described above. The rock consists chiefly of quartz, accompanied by small amounts of biotite, cordierite and potash-feldspar. Quartz crystals, form-

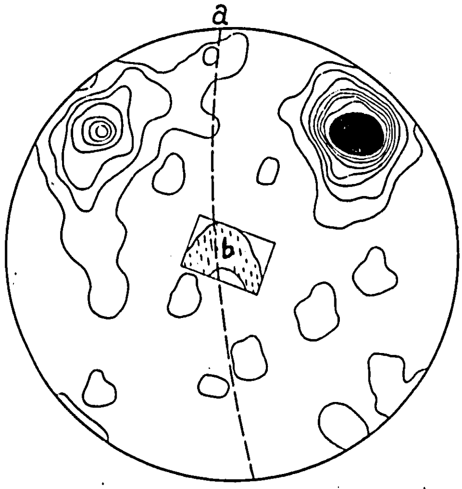

FIG. 23. 500 c-axes of quartz in folded siliceous banded gneiss from Ayugaeri (Sp. 57 112803).
Contours: 8-7-6-5-4-3-2-1 %, Max. 13%.

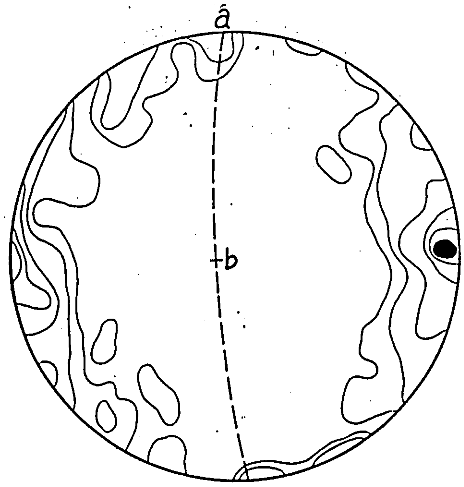

FIG. 24. 200 poles of biotite cleavage in the siliceous banded gneiss from Ayugaeri.
Contours: 10-8-6-4-2-1 %, Max. 12%.

ing the matrix of the rock, are rounded and show granular texture.

Fig. 21 is based on the measurement of 400 grains of quartz in a (*bc*) section. The quartz pattern shows weak concentration and no significant symmetry is detectable.

200 flakes of biotite were measured. Fig. 22 shows the biotite diagram. Marked dimensional orientation is shown with a strong maximum which nearly coincides with the pole of the foliation plane. Points are dispersed in partial girdles.

Specimen 57112803

Locality: Ayugaeri, Hikari City.

Megascopically, the rock is intensely folded and strong lineation is developed oblique to the axis *b* on the micaceous bands. The rock consists of abundant quartz and a small biotite. Large elongated quartz grains (0.6~2mm in length) are fractured into fine needles (about 0.05mm in length) by the post-crystalline deformation. The longest demension of quartz needle is nearly parallel to the axial plane S_2. Biotite occurs as small flakes scattered in the quartz matrix. The thin section was cut at the right angle to the fold axis (*b*).

500 c-axes of quartz at the hinge of a fold, as shown at the center of fig. 23, were measured. The quartz diagram is shown in fig. 23. Two strong and sharp maxima, with different concentration, occur symmetrically on either side of the axial plane.

Biotite diagram was made on the measurement of flakes in the matrix, and those in the folded micaceous layers were omitted. Fig. 24 shows the orientation of 200 poles of biotite flakes. The strong maximum coincides with the pole of the axial plane, showing slight dispersion in a partial (*ac*) girdle. It is doubtless that the biotite in the matrix was formed under the stress condition responsible for the formation of the fold with the axial plane S_2.

GRANITIZED BANDED GNEISS

In the central and southern parts of the region, the banded gneisses suffered the granitization, and were gradually changed to the gneissic granodiorites. Measurements were made on the granitized siliceous banded gneisses with plane foliation or folded near the contact with the gneissic granodiorites. Granitized pelitic banded

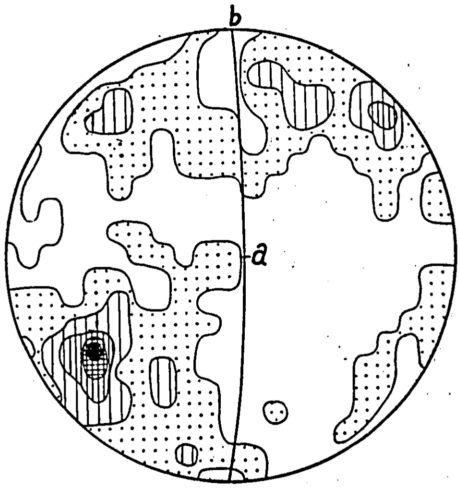

FIG. 25. 508 c-axes of quartz in the granitized siliceous banded gneiss from Ôkubo (Sp. 57102703)., No selection of grains was made. Contours: 5-4-3-2-1%.

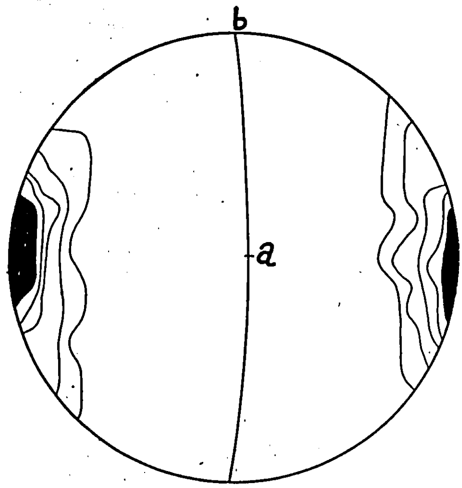

FIG. 26. 200 poles of biotite flakes in the granitized siliceous banded gneiss from Ôkubo (Sp. 57102703). Contours: 13-10-7-4-1%, Max. 16%.

gneiss and pelitic injection gneiss were also examined.

Siliceous Banded Gneiss

Specimen 57102703

Locality: Ôkubo, Ôbatake Town.

Megascopically a distinct plane foliation and a lineation parallel to the fold axis are developed. The rock is composed of abundant quartz and small amounts of muscovite, biotite and wollastonite. Quartz, forming the matrix, varies in grain size, showing an effect of granitization. Quartz grains range from 0.002 to 4 mm in length and are commonly elongated, the ratio between the longest and the shortest dimensions in the (*bc*) section being 1.56: 1=*b*: *c*. Petrographically the rock shows no effect of feldspathization, but it lies at a few meters from the migmatitic granodiorite with concordant relation. Small biotite flakes are scattered in the matrix.

508 c-axes of quartz were measured for the grains of a fine-grained layer concordant to the foliation consisting essentially of quartz. Fig. 25 shows the quartz diagram. The diagram indicates pronounced maximum in the third quadrant. The concentration of maxima is not identical, but their positions correspond to the position IV after SANDER and FAIRBAIRN. The periphery of the diagram is vacant with respect to the c-axis of quartz.

200 poles of the cleavage of biotite were measured and plotted in fig. 26. Marked dimensional orientation is shown with a strong maximum at *c*. Some poles are dispersed in a partial (*ac*) girdle.

Specimen 58022502

Locality: Kurokui, Yanai City.

The rock occurs with the aplitic dike (Specimen 58022503) cutting the banded gneiss discordantly.

Megascopically compositional banding is marked owing to the alternation of biotite-rich layers and quartzo-feldsparthic one. Lineation of *b*-type is developed on the foliation surface. The rock consists chiefly of quartz, plagioclase, potash-feldspar, biotite and garnet. Quartz forming the matrix of the rock occurs as irregularly shaped grains ranging from 0.5 to 5.0 mm in diameter, showing undulatory extincton. Biotite flakes are well aligned on the foliation.

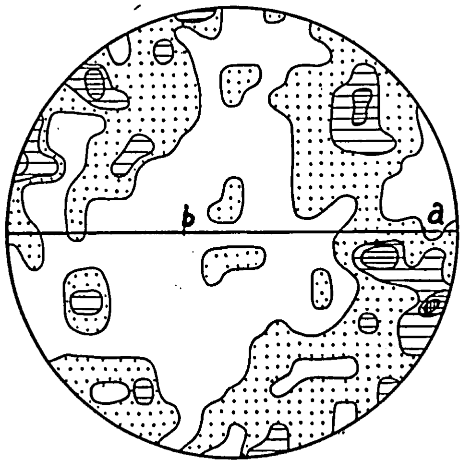

FIG. 27. 400 c-axes of quartz in the granitized siliceou banded gneiss from Kurokui (Sp. 58022502). Contours: 4-3-2-1%.

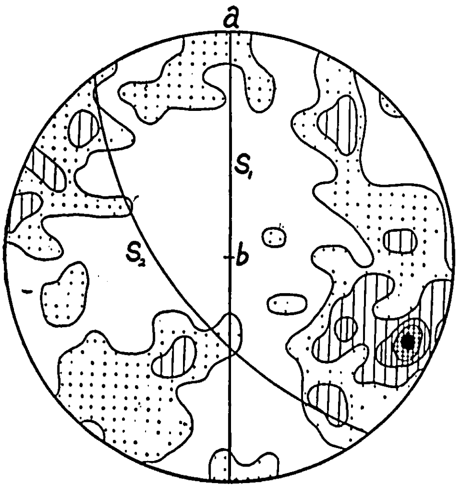

FIG. 28. 500 c-axes of quartz in the granitized siliceous banded gneiss from the coast of Yokomi (Sp. 58050401).
Contours: 5-4-3-2-1%.

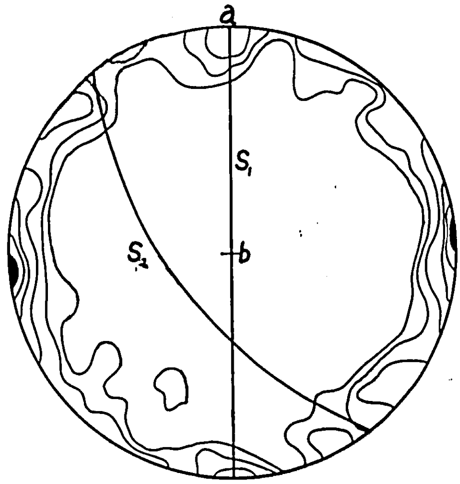

FIG. 29. 200 poles of biotite cleavage in the granitized siliceous banded gneiss (Sp. 58050401).
Contours: 10-8-6-4-2-1%, Max. 12%.

400 c-axes of quartz were measured without selection of grains. Fig. 27 shows the microfabric diagram of quartz. The distribution of c-axes is roughly peripheral, that is, normal to *b*-axis.

Specimen 58050401

Locality: Coast from Ypkomi to Himi, Ôshima.

Megascopically distinct plane foliation and remarkable lineation due to the preferred orientation of biotite are observed. Porphyroblastic quartz grains are elongated parallel to S_2 which is oblique to the foliation S_1. The rock consists of quartz, plagioclase, biotite and muscovite. The porphyroblastic quartz ranges from 4.0 to 6.0 mm in diameter. Medium and small grains are commonly elongated parallel to the foliation.

500 c-axes of quartz were measured without selection of grains. The fabric diagram is shown in fig. 28. The dsitribution of the axes is roughly peripheral and shows an incomplete girdle. Chief maxima lie near the periphery.

200 poles of the cleavage of biotite were measured. The diagram is shown in fig. 29. It shows complete girdle perpendicular to *b* with a maximum indicating strong orientation of flakes parallel to the megascopic schistosity S_1. The submaxima on or oblique to S_1 are due to small isolated biotitie flakes scattered in the matrix.

Specimen 58030201

Locality: Coast from Heta to Yokomi, Ôshima.

The sample occurs near the contact with the Okiura gneissic granodiorite.

Megascopically the foliation is strongly folded. Axial planes of folds are parallel. There is no other megascopically visible secondary *s*-surface parallel or oblique to the axis of folds. The rock consists of abundant quartz and small amounts of biotite, plagioclase (albite) and muscovite (fig 4, A). Quartz forms the matrix. The grains range from 0.008 to 2 mm in length. The small grains are more or less equidimensional, while the medium or coarse grains are commonly elongated, the ratio of the longest to the shortest dimensions being 1.45 : 1 in (*ac*) section, and 1.65 : 1 in (*bc*) section. At the hinge of fold biotite layers are orientated parallel to the compositional banding. Pagioclase which is almost always twinned after the albite law is lath-shaped and arranged parallel to s_1.

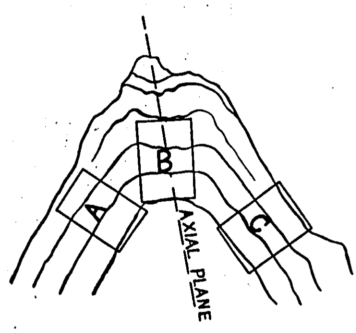

FIG. 30. Sketch of a folded sample of the granitized siliceous banded gneiss at the coast from Heta to Yokomi (Sp. 58030201). The orientation of quartz and biotite in areas A, B and C were measured.

As shown in fig. 30 three sections from the folded specimen were selected for fabric analysis: two (A, C) from the limbs of the fold, and the other (B) from the hinge.

Figs. 31 to 33 are the microfabric diagrams of quartz in the areas A, B and C of fig. 30. b is parallel to the axis of the fold. The patterns of these diagrams resemble each other. The position of the chief maxima is consistent through these diagrams with respect to the axial plane of the fold. The pattern of each diagrams cannot be readily characterized, but may be defined as monoclinic. The preferred orientation of c-axes of quartz is thus homogeneous throughout the area in fig. 30 without respect to the fold, in other words, the fold is "non-unrollable" (SANDER, 1951).

The fabric diagrams of biotite in each field of fig. 30 are shown in figs. 34 to 36. Each diagram represents the preferred orientation of 200 flakes of biotite which constitutes the banding in the quartzose layer. Each diagram shows *ac*-girdle with several maxima, a part of which corresponds to the megascopic foliation, but there can be found no distinct submaximum corresponding to the axial plane. The main maxima of each diagram do not strictly coincide with the poles of various *s*-srufaces or axial planc for respective sections. The diagram of the hinge, Fig. 35, shows a complete *ac*-girdle. Since the foliation surface (S_1) is not exactly plane in the thin section, the maxima do not correspond either to the pole of the mean position of S_1 or to that of the axial plane determined on the hand specimen. Therefore, the girdle pattern of biotite is in part due to the unhomogeneity of biotite fabric, namely, corrugation of the micaceous layers.

The collective diagram, fig. 37, in which all the points in figs. 34 to 36 are plotted and contoured, shows more complete girdle, showing slightly higher orientation at the position perpendicular to the axial plane.

Specimen 5806301

Locality: Tana, Kumage Peninsula.

The occurrence is nebulitic, and the specimen represents a more granitized siliceous banded gneiss in the Ôbatake gneissic granodiorite.

Megascopically the foliation due to the alternation of melanocratic and leucocratic layers and the lineation due to the parallel orientation of biotite flakes are well developed. The rock consists of quartz, pla-

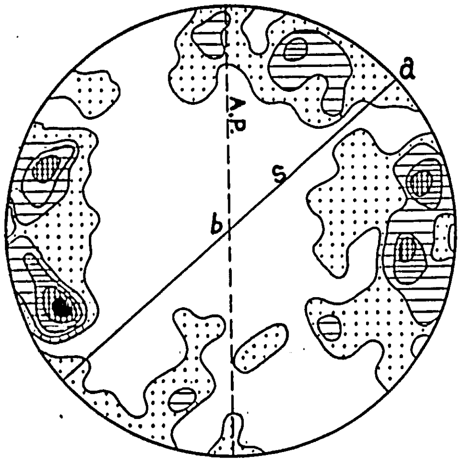

Fig. 31. 500 c-axes of quartz from area A in fig. 30. Contours: 5-4-3-2-1%.

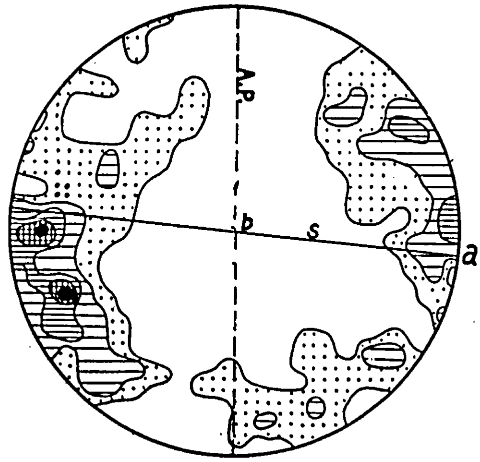

Fig. 32. 600 c-axes of quartz from area B in fig. 30. Contours: 5-4-3-2-1%.

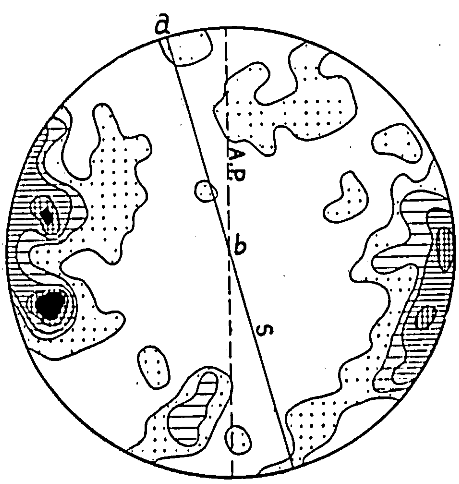

Fig. 33. 500 c-axes of quartz from area C in fig. 30. Contours: 5-4-3-2-1%, Max. 6.1%.

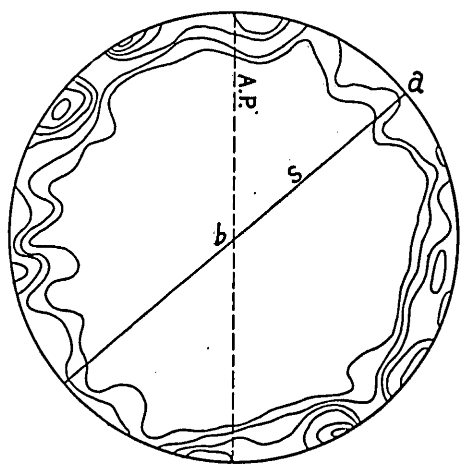

Fig. 34. 200 poles of biotite cleavage from area A in fig. 30. Contours: 6-5-4-3-2-1%.

gioclase, biotite, cordierite and garnet.

500 c-axes of quartz were measured and the fabric diagram is shown in fig. 38. Main maxima are situated near the position IV by Sander. The diagram shows nearly rhombic symmetry.

200 poles of biotite flakes were measured and plotted in fig. 39. Marked dimensional orientation is shown with the strong maximum in *c*. There are faint submaxima on the foliation plane.

Specimen 57102801

Locality: Ôkubo, Ôbatake.

The rock occurs as a thin nebulitic film in the Ôbatake gneissic granodiorite. It consists of quartz, plagioclase, potash-feldspar, muscovite, biotite and cordierite. Quartz occurring as elongated grains parallel to the foliation in the *b* section is from 0.2 to 6.0mm in length, showing strong undulatory extinction.

500 c-axes of quartz were measured without selection on grains. The diagram shown in fig. 40 indicates

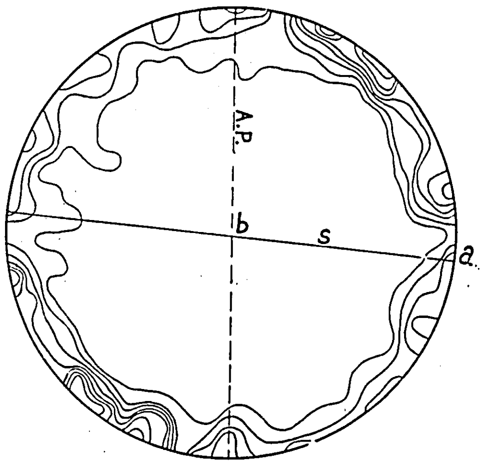

FIG. 35. 200 poles of biotite cleavage from area B in fig. 30.
Contours: 7-6-5-4-3-2-1 %.

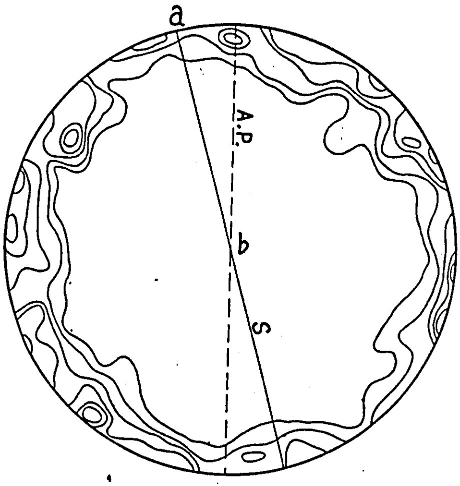

FIG. 36. 200 poles of biotite cleavage from area C in fig. 30.
Contours: 5-4-3-2-1 %.

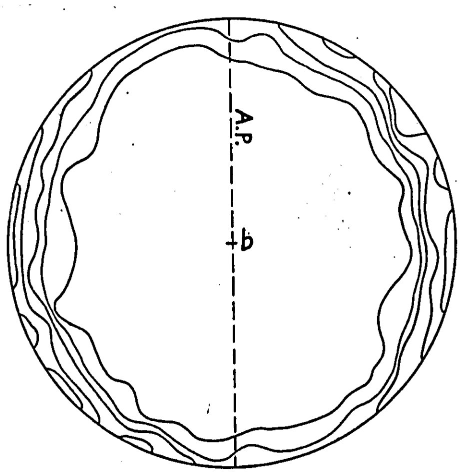

FIG. 37. Collective diagram of biotite. 600 poles of biotite cleavage from areas A, B and C from fig. 30. Contours: 5-4-3-2-1 %.

nearly peripheral distribution normal to *b* and roughly rhombic symmetry.

The biotite diagram in fig. 41 represents 150 poles of flakes. It shows an incomplete girdle, with a maximum indicating strong preferred orientation of flakes parallel to the megascopic schistosity *ab*. Some submaxima suggest the presence of *s*-surfaces across the foliation.

Pelitic Banded Gneiss

Specimen 58021501

Licality: Befu, Marifu.

Megascopically platy banding due to the alternation of micaceous and quartzo-feldspathic layers is distinct. The lineation is strongly developed within the micaceous layers. Quartzo-feldspathic veins are

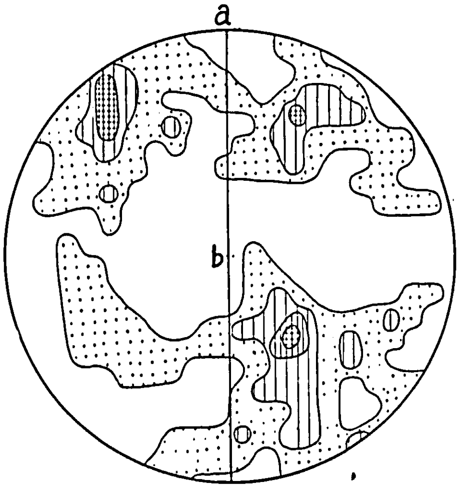

FIG. 38. 500 c-axes of quartz in the granitized siliceous banded gneiss from Tana (Sp. 58060301).
Contours: 4-3-2-1%.

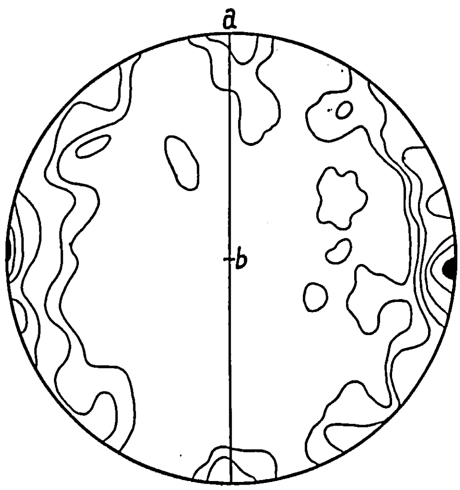

FIG. 39. 200 poles of biotite cleavage in the granitized siliceous banded gneiss from Tana (Sp. 58060301).
Contours: 10-8-6-4-2-1%.

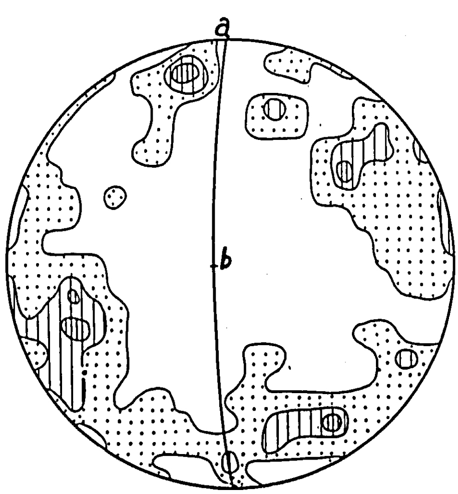

FIG. 40. 500 c-axes of quartz in the granitized semi-pelitic banded gneiss from Ôkubo (Sp. 57102801).
Contours: 3-2-1%, Max. 3.9%.

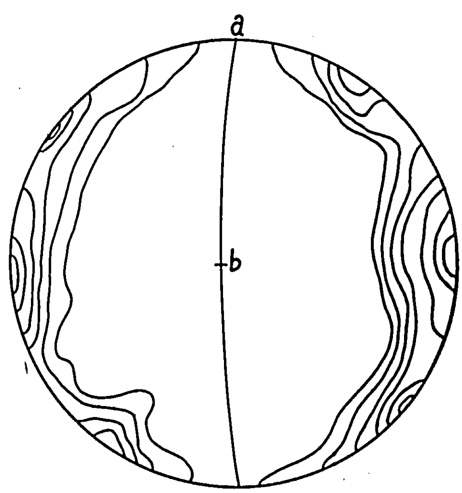

FIG. 41. 150 poles of biotite cleavage in the granitized semi-pelitic banded gneiss from Ôkubo (Sp. 57102801).
Contours: 6-5-4-3-2-1%.

developed, often showing ptygmatic folds. The rock consists chiefly of quartz, plagioclase, potash-feldspar and biotite.

Quartz diagrams were prepared separately for the micaceous layer and the quartzo-feldspathic vein. Fig. 42 is based upon the measurements of 300 grains of quartz in the micaceous layer. The diagram shows nearly orthorhombic symmetry. Weak maxima lie near the position IV after SANDER.

Fig. 43 is based upon the measurements of 300 c-axes of quartz in the quartzo-feldspathic vein. The diagram shows also a nearly orthorhombic symmetry. Some maxima lie near the periphery. It must be noted that the fabric diagrams of quartz for the micaceous layer and the quartzo-feldspathic layer are

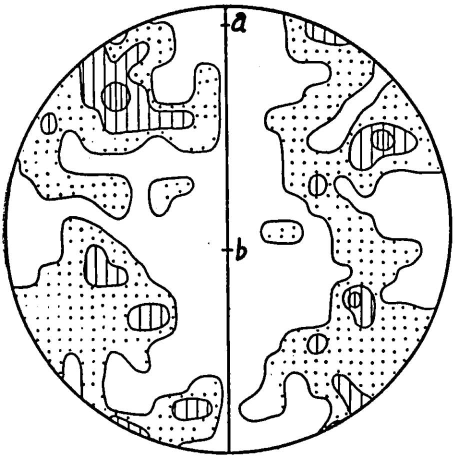

FIG. 42. 300 c-axes of quartz in the micaceous layers of the granitized pelitic banded gneiss from Befu (Sp. 58021501). Contours: 3-2-1%, Max. 3.9%.

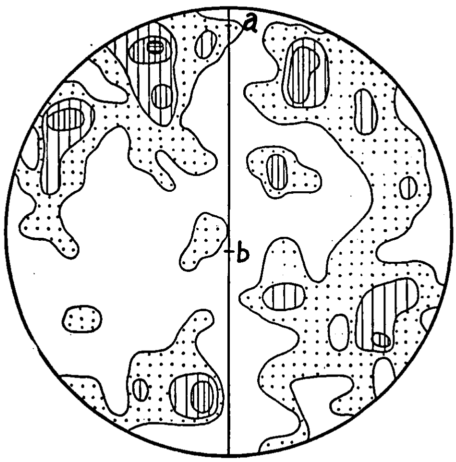

FIG. 43. 300 c-axes of quartz in the quartzo-feldspathic veins of Sp. 58021501. Contours: 4-3-2-1%.

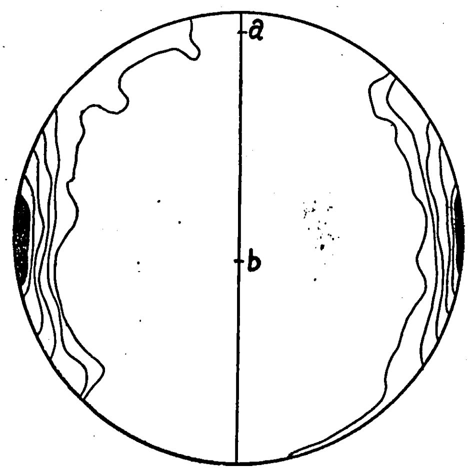

FIG. 44. 200 poles of biotite cleavage in the granitized pelitic banded gneiss from Befu (Sp. 58021501). Contours: 15-12-9-6-3-1%.

resemble each other in essential characters.

FIG. 44 shows the fabric diagram of biotite measured irrespective of banding. Biotite flakes show strong preferred orientation parallel to the schistosity (*ab*).

Specimen 58030204

Locality: Coast from Heta to Yokomi.

The rock occurs as thin layers within the granitized siliceous banded gneiss (Specimen 58030202). It consists of quartz, plagioclase, potash-feldspar, biotite and sillimanite.

400 c-axes of quartz in the quartz-rich band were measured. The diagram is shown in fig. 45. The pattern is characterized by small circle girdle perpendicular to *b*, and maxima lie perpendicular as well as parallel to the foliation.

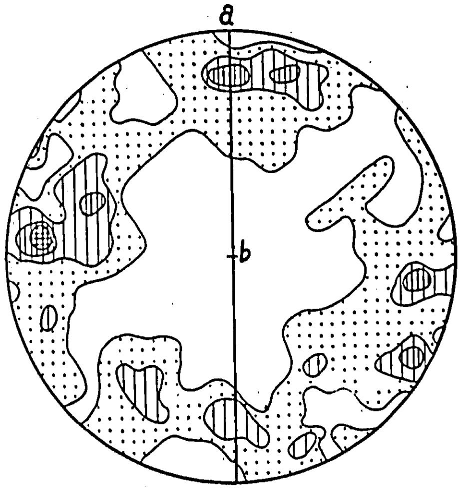

FIG. 45. 400 c-axes of quartz in the granitized pelitic banded gneiss from the coast of Yokomi (Sp. 58030204).
Contours: 4-3-2-1%.

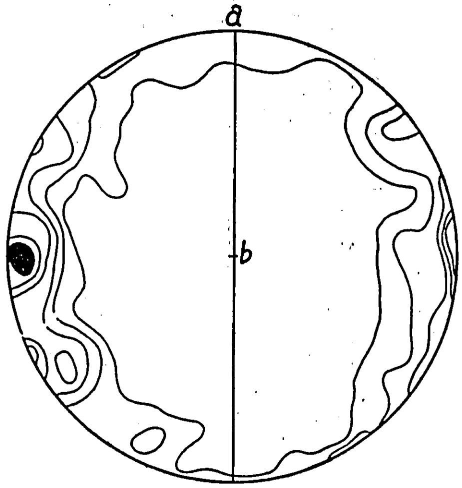

FIG. 46. 200 poles of biotite cleavage in the granitized pelitic banded gneiss from the coast of Yokomi (Sp. 58030204).
Contours: 10-8-6-4-2-1%.

200 poles of biotite flakes were measured and plotted in fig. 46. The diagram shows an *ac*-girdle with the maximum coinciding with *c*.

GRANODIORITE

Older Granodiorite

Fabric analyses were made for six orientated specimens of the older gneissic granodioritic complex and one specimen of the younger granite. The specimens of the older granodiorite were chosen in order that they represent the typical types. They were collected near the banded gneisses the fabric of which has been studied above, so that the fabric studies of them reveal structural relations between the gneissic granodiorites and the banded gneisses.

Specimen 57101301

Locality: Ôkubo, Ôbatake.

The rock is medium-grained, and the foliation due to the alternation of mica-rich layers and quartzo-feldspathic layers is well developed. Lineation is weak. The rock consists chiefly of quartz, plagioclase, biotite and potash-feldspar.

200 c-axes of quartz were measured without selection of grains. Fig. 47 shows the quartz diagram. Four maxima which amount to 5 percent are observed approximately in the position IV. The pattern shows orthorhombic symmetry.

150 poles of the cleavage of biotite were measured and plotted with the result shown in fig. 48. The diagram shows the girdle parallel to (*ac*), and broad maximum occurs in *c*. Some points are distributed outside the girdle.

Plagioclase is mostly twinned after the albite law. Statistically the twinning of the plagioclase is characterized by the ratio of A : U : C=92.1 : 6.1 : 1.8 after the classification proposed by M. GORAI (1950). 150 poles of twinning plane (010) of plagioclase were measured. The diagram is shown in fig. 49. Marked dimensional orientation is shown with strong maximum in *c*. Some poles are dispersed along (*ac*), forming a partial girdle. There is also a submaximum in *a*.

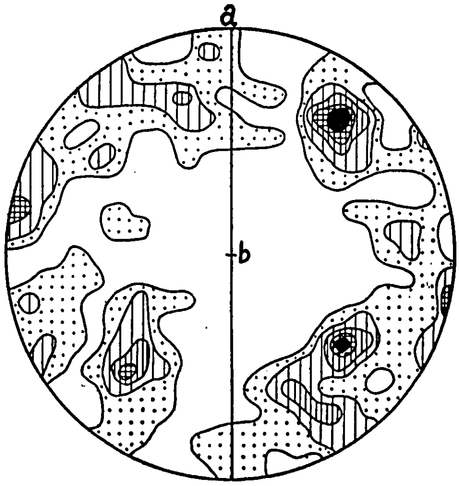

FIG. 47. 200 c-axes of quartz in the Ôbatake gneissic granodiorite from Ôkubo (Sp. 57101301).
Contours: 5-4-3-2-1%, Max. 6%.

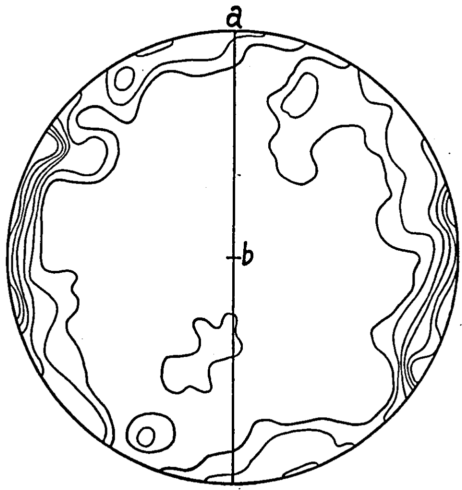

FIG. 48. 150 poles of biotite cleavage in the Ôbatake gneissic granodiorite from Ôkubo (Sp. 57101301).
Contours: 6-5-4-3-2-1%.

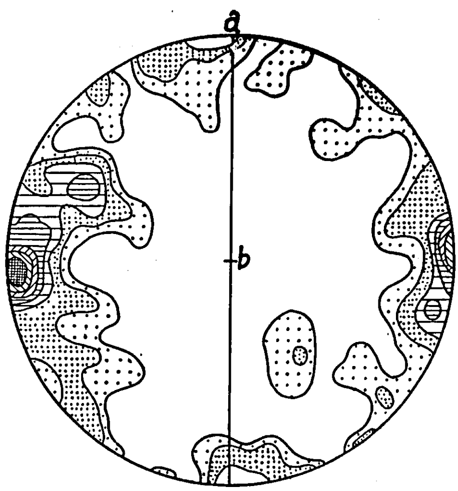

FIG. 49. 150 poles of albite-twin (010) plane of plagioclase in the Ôbatake gneissic granodiorite.
Contours: 7-6-5-4-3-2-1%.

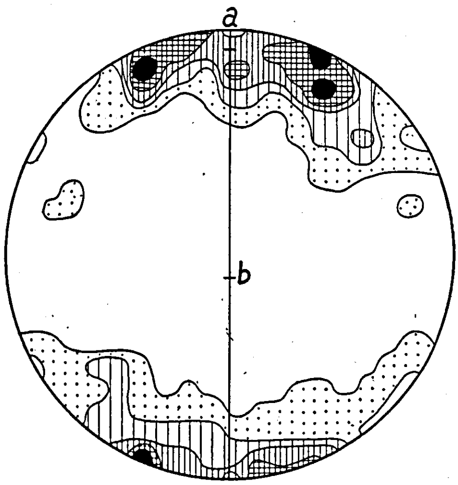

FIG. 50. 400 c-axes of quartz in the Gokenya gneissic granodiorite (Sp. 58021502).
Contours: 5-4-3-2-1%.

Specimen 58021502

Licality: Gokenya, Hikari City (pl. 16-6; pl. 20-5)

The rock is fine-grained, and characterized by distinct foliation, and especially by strong lineation owing to the preferred orientation of biotite and quartz. It consists of abundant quartz, plagioclase, biotite and small amounts of potash-feldspar and sphene. Quartz is elongated parallel to *b*. 400 c-axes of quartz were measured. Fig. 50 shows the fabric diagram of quartz. The pattern shows distinct rhombic symmetry. Maxima of the concentration are normal to *b*, nearly coinciding to the position II after SANDER, and incomplete (*ac*)-girdle is shown.

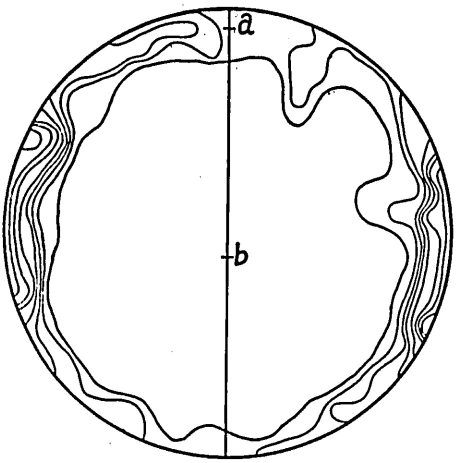

FIG. 51. 200 poles of biotite cleavage in the Gokenya gneissic granodiorite (Sp. 58021502).
Contours: 8-7-6-5-4-3-2-1%.

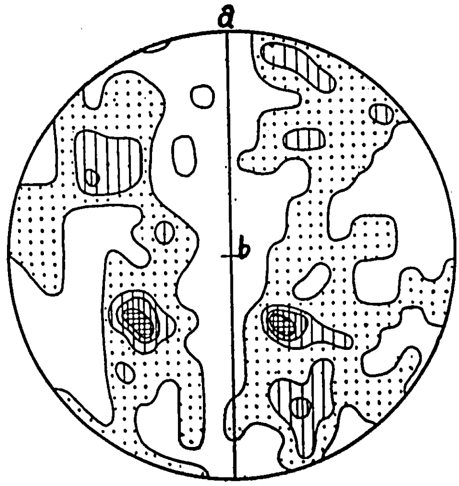

FIG. 52. 400 c-axes of quartz in the Ôbatake gneissic granodiorite from Tana (Sp. 58060302).
Contours: 4-3-2-1%.

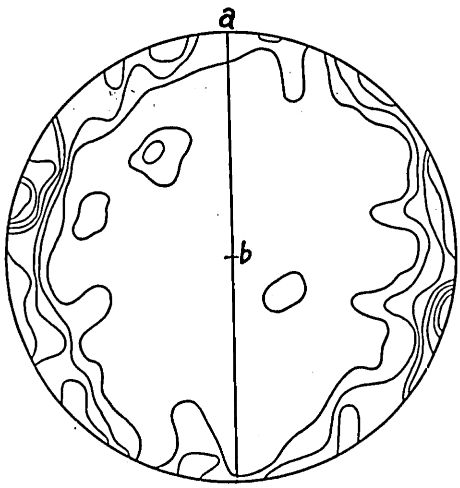

FIG. 53. 200 poles of biotite cleavage in the Ôbatake gneissic granodiorite from Tana.
Contours: 7-6-5-4-3-2-1%.

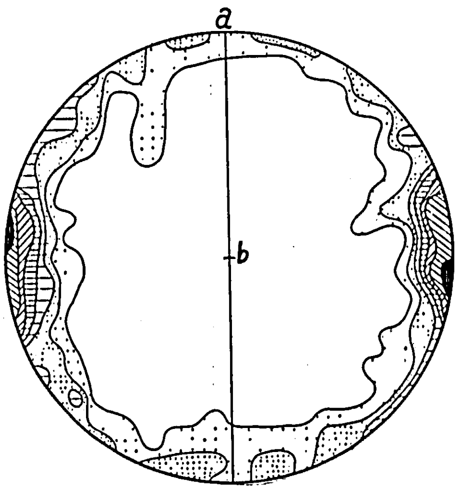

FIG. 54. 200 poles of albite-twin (010) plane of plagioclase in the Ôbatake gneissic granodiorite from Tana.
Contours: 7-6-5-4-3-2-1%.

The biotite diagram in fig. 51 is based on the measurement of 200 poles of cleavage. Marked dimensional orientation is shown with a strong maximum in *c*. Biotite diagram shows a complete girdle parallel to *ac*.

Specimen 58060302

Locality: Tana, Kumage Peninsula.

The specimen was collected from the same outcrop as that of specimen 58060301.

The rock is medium-grained, and has a remarkable foliation consisting of alternating layers of dark min-

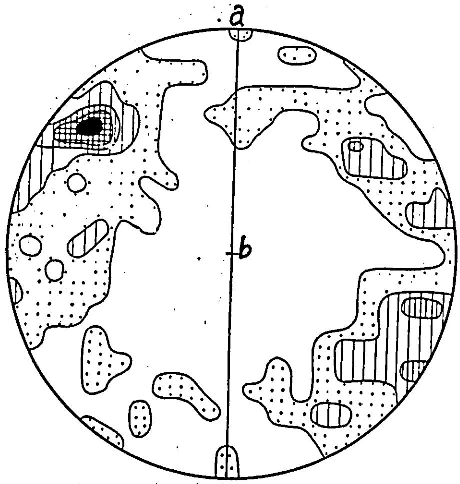

FIG. 55. 400 c-axes of quartz in the Okiura gneissic granodiorite from Heta (Sp. 58030203).
Contours: 5-4-3-2-1%.

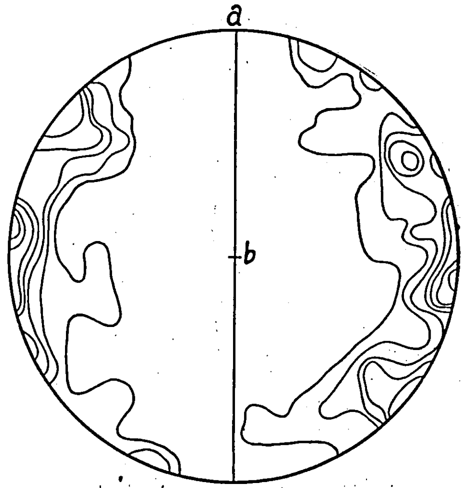

FIG. 56. 200 poles of biotite cleavage in the Okiura gneissic granodiorite from Heta (Sp. 58030203).
Contours: 7-6-5-4-3-2-1%.

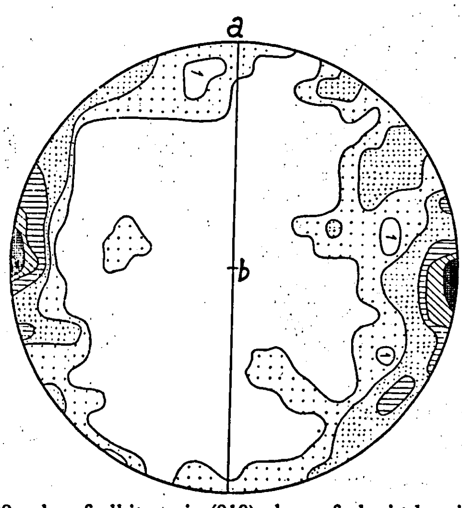

FIG. 57. 200 poles of albite-twin (010) plane of plagioclase in the Okiura gneissic granodiorite from Heta (Sp. 58030203).
Contours: 10-8-6-4-2-1%.

erals and felsic ones and a faint lineation due to the orientation of biotite flakes on the foliation plane. The rock consists of quartz, plagioclase, biotite and potash-feldspar.

400 c-axes of quartz were measured. The diagram is shown in fig. 52. Chief maxima lie in the position IV. The distribution of *c*-axes shows two incomplete symmetrical (h0l) girdles. Thus, the fabric pattern has an approximately orthorhombic symmetry. It is noteworthy that the fabric pattern of the granodiorite closely resembles that of the granitized siliceous banded gneiss which comes into contact with the former.

The fabric diagram of biotite, shown in fig. 53, is based on the measurement of 200 poles of cleavage of flakes. The diagram shows an incomplete *ac* girdle with the maximum inclined a few degrees to *c*, and submaxima occurring at several points on *ac*, that showing the presence of indefinable *s*-surfaces (h0l) in-

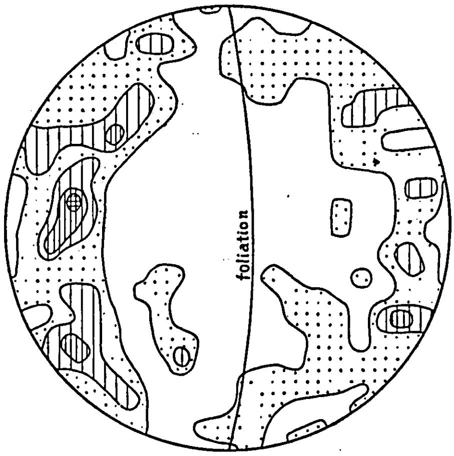

FIG. 58. 340 c-axes of quartz in the Gamano gneissic granodiorite from Mukuno (Sp. 58050403). Contours: 4-3-2-1%.

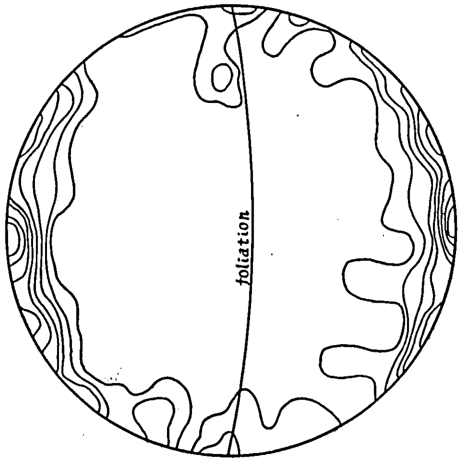

FIG. 59. 200 poles of biotite cleavage in the Gamano gneissic granodiorite from Mukuno (Sp. 58050403). Contours: 8-7-6-5-4-3-2-1%.

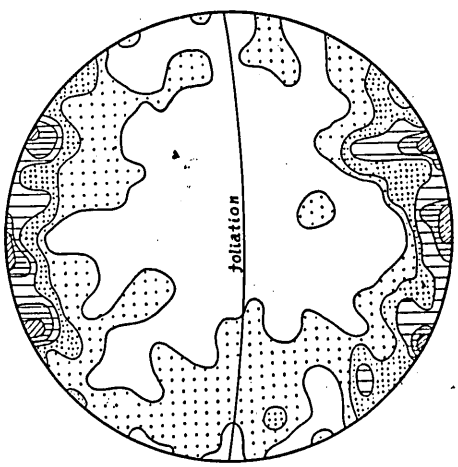

FIG. 60. 200 poles of albite-twin (010) plane in the Gamano gneissic granodiorite from Mukuno (Sp. 58050403). Contours: 5-4-3-2-1%.

FIG. 62. 400 c-axes of quartz in aplitic dyke from Kurokui (Sp. 58022503). Contours: 5-4-3-2-1%.

clined to *ab*.

Measurements of plagioclase were made for 200 poles of albite-twinning plane (010). The fabric diagram is shown in fig. 54. The distribution of the pole of (010) has a tendency to form (*ac*) girdle. The frequency of twinning type of plagioclase of the rock is as follows: A twin=88.6%, U twin=4.4%, and C twin=7.0, according to the scheme of classification by GORAI (1950).

Specimen 58030203

Locality: Coast from Heta to Yokomi, Ôshima Town.

The locality is same as that of specimen 58030202. The specimen was collected from the outcop 30 meters apart from the granitized siliceous banded gneiss.

The rock is medium-grained, and the remarkable foliation and lineation owing to the orientation of biotite are developed. It consists of quartz, plagioclase, potash-feldspar and biotite. Quartz grains are commonly elongated in the foliation.

400 c-axes of quartz were measured without selection of grains. Fig. 55 shows the fabric diagram of quartz. The distribution of c-axis makes an incomplete girdle about *b* which coincides with the lineation. The maximum concentration lies near the periphery.

The fabric diagram of biotite in fig. 56 represents the measurement of 200 poles of cleavage of flakes. The pattern is characterized by the maximum in *c* corresponding to the megascopic foliation, and by subordinate concentrations in (*ac*), indicating the presence of indefinable *s*-surfaces (h0l).

200 poles of albite-twinning plane of plagioclase were measured and the fabric diagram is shown in fig. 57. The frequency of twinning types of plagioclase in the thin section is as follows: A twin=84.0%, Ca twin=8.0%, and U twin=18.6%. The albite twinning planes are generally oriented parallel to the megscopic foliation, but partial girdle in *ac* is also shown in the diagram.

Specimen 58050403

Locality: Coast from Mukuno to Migama, Ôshima Town.

The specimen represents a typical one collected from the Gamano gneissic granodiorite. The rock is medium-grained, showing remarkable foliation but no lineation can be detected. It consists of quartz, plagioclase, potash-feldspar and biotite. The thin section was made perpendicular to the megascopic foliation. The foliation is hardly detectable under the microscope.

340 c-axes of quartz were measured without selection of grains. Fig. 58 shows the fabric diagram of quartz. The pattern is less regular but still indicates an incomplete small-circle girdle perpendicular to *b* with some maxima. The pattern has nearly orthorhombic symmetry.

200 poles of cleavage of biotite flakes were meaured and the fabric diagram is shown in fig. 59. The pattern shows preferred orientation parallel to the foliation. Some poles are dispersed in (*ac*).

200 poles of albite-twinning plane of plagioclase were measured and the fabric diagram is shown in fig. 60. The albite twinning planes are roughly arranged parallel to the megascopic foliation, and some are dispersed forming a partial ac girdle. The frequency of the twinning type of plagioclase in the thin section is as follows: A twin=81.8%, C twin=8.6%, and U twin=9.6%.

The patterns of quartz, biotite and plagioclase are less regular than those of other types of older granodiorites.

Specimen 58022503

Locality: Kurokui, Yanai City.

The rock occurs as an aplitic dike of about 2.0 meters in width, discordantly cutting the granitized siliceous banded gneiss (Specimen 58022502) as shown in fig. 61. Megascopically the rock is medium-grained and leucocratic. Parallel orientation of biotite flakes is oblique to the surface of the boundary to the siliceous banded gneiss. The rock consists chiefly of quartz, potash-feldspar and biotite. The thin section was made approximately perpendicular to the foliation shown by the parallel arrangement of biotite flakes.

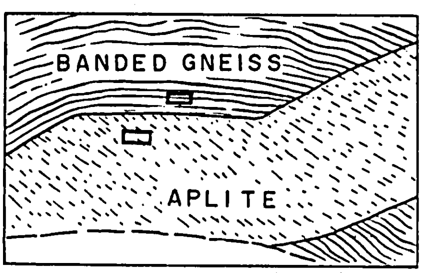

Fig. 61. Aplitic dyke cutting discordantly the granitized banded gneiss (Sp. 58022502). Kurokui, Yanai.

400 c-axes of quartz were measured, and the fabric diagram is shown in fig. 62. There are four maxima with rather higher concentration, roughly arranged symmetrically. The pattern has nearly orthorhombic symmetry. Notable similarity exists with respect to the quartz diagram between the aplitic dike and the granitized siliceous banded gneiss.

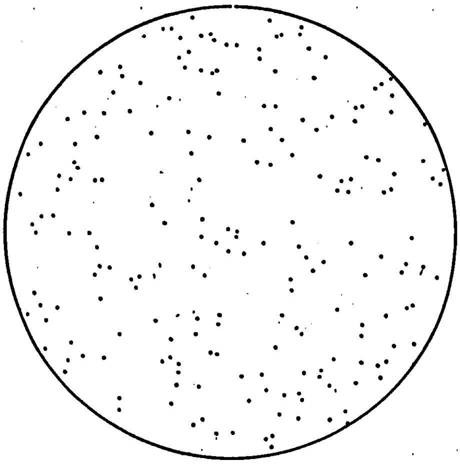

FIG. 63. 200 c-axes of quartz in the fine-grained granite from Ihonosho, Yanai (Sp. 51102901).

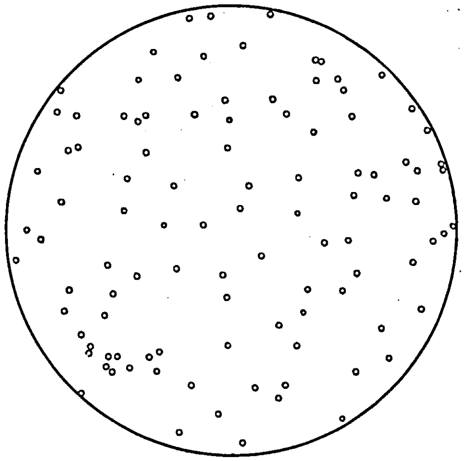

FIG. 64. 100 poles of biotite cleavage in the fine-grained granite from Ihonosho, Yanai. (Sp. 51102901).

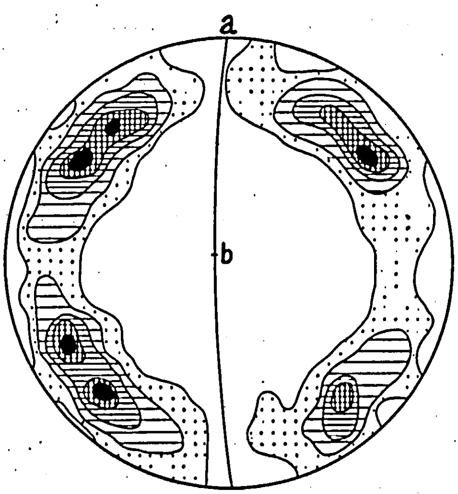

FIG. 65. 400 c-axes of quartz in siliceous biotite schist from Shigino, Iwakuni City. (after T. NUREKI)

Younger Granite

Specimen 51102901

Locality: Oda, Ihonoshô, Yanai City.

The sample was collected from fine grained granite forming a sheet-like mass. The rock is homogeneous. It consists of quartz, plagioclase, potash-feldspar, and biotite.

200 c-axes of quartz were measured, and plotted in an equal-area-projection with the result shown in fig. 63. The distribution of c-axes does not show any definable pattern or symmetry.

100 poles of cleavage of biotite flakes were measured. Fig. 64 shows the distribution of poles. Preferred orientation of biotite flakes can not be observed.

Summary and Interpretation of the Diagrams

Summarizing the characteristic features of the fabric of quartz, biotite and plagioclase, the author attains to the following summary and interpretations.

1. *Quartz fabric*

a. The quartz diagrams of the siliceous banded gneisses proper show weak concentration, being less regular than granitized banded gneisses. The maxima tend to lie near the IV position. The relation of the maxima to *s*-surface is obscured. The patterns show no symmetry in respect to the foliation or lineation.

b. The folded sample of Ayugaeri (fig. 23) which shows high concentration and monoclinic symmetry is the only exception. This pattern is interpreted to be owing to the post-crystallization mylonitization.

c. The diagrams of siliceous banded gneisses which have been suffered granitization show stronger concentration attaining to 5 percent per 1 percent area than siliceous banded gneisses proper. These diagrams show generally incomplete *ac* girdle, and show a tendency to lie from the position of IV or VI zones (Fairbairn, 1954) to the periphery. The symmetry is roughly monoclinic.

d. As seen in figs. 31 to 33, the quartz fabrics of folded samples are homogeneous with regard to the axial plane. Although megascopically the folding is neither flexural nor shear type, it seems to have been caused by the shearing parallel to the axial plane.

e. The pattern of the fabric diagrams of granitized pelitic banded gneisses closely resembles that of granitized siliceous banded gneisses. From megascopic structures, it is obvious that the foliation of the pelitic gneiss coincides with the shear plane. Accordingly the orientation of quartz of biotite-rich layer may have been developed under shearing. From that fact that the patterns of quartz from the biotite-rich layers and the quartzo-feldspathic layers resemble each other, it is evident that the quartzo-feldspathic layers were formed during the granitization, perhaps under the shear condition.

f. The fabric diagrams of quartz of migmatitic gneissic granodiorites show strong concentration like those of granitized banded gneisses. The pattern of the samples having distinct foliation and lineation shows roughly rhombic symmetry in respect to the foliation. The maxima of concentration tend to lie in the II or IV zone (Fairbairn). The diagrams tend to show *ac* girdle normal to the lineation.

g. As shown in fig. 62, the quartz pattern of younger intrusive granodiorite does not show any preferred orientation.

With regard to the mechanism of quartz orientation in tectonite, two principal theories, *i.e.*, the fracture hypothesis advocated by Sander (1930) and fostered by Griggs and Bell (1938), and the translation hypothesis maintained by Sander and by Schmidt (1932), have been known. We have hitherto obtained no comprehensive theory which explains the mechanism of quartz orientation and the situation of the maxima of quartz fabric diagrams.

Recently Kojima and Suzuki (1957) explained the rule of quartz orientation of quartzose seam in highly fissile black-schist of the Kiyomizu Tectonic Zone, Central Shikoku, Southwestern Japan. They explained that r(10$\bar{1}$1) and/or z(01$\bar{1}$1) of quartz lie on the shear plane, and that the displacement of upper layers on these lattice plane is downward from the *c*-axis. This interpretation, however, cannot be applied to these diagrams under consideration, because the pattern of fabric diagrams is so complicated.

According to Turner (1951, 1957) and De Sitter (1956), the symmetrological feature of the fabric pattern is most valuable for the kinematic interpretation.

With regard to foliated granitic rocks it is reported by many investigators that quartz commonly forms girdle pattern normal to the lineation (Osborn, 1939; Gault, 1945; Cloos, 1947). Osborn interpreted that the quartz fabric in tonalite was produced by rotation of mineral grains in *ac*-plane with the axis *b* and the structure is a result of stress exerted on the rock both during and after solidification. Cloos (1947) mentioned that axis of quartz girdle coincides with that of mica girdle and the megascopic lineation, and that it is normal to the principal direction of movement and parallel to the subordinate direction. He described also that quartz is the last crystallized mineral. Gault (1945) concluded that quartz diagrams in Pinkeville quartz-diorite may be related to *s*-plane determined statistically, and grains are thought to rotate into shear planes with long axis parallel to the direction of movement or *a*.

Quartz fabric patterns of the gneissic granodiorites and granitized banded gneisses in the region have similar characteristics, *i.e.*, *ac* girdle normal to the lineation *b* having the maxima in the IV position or near the *ac* plane, the orientation of quartz may have intimate relation to *s*-plane determined megascopically or statistically.

Nureki (1960) reported that the quartz diagram of siliceous biotite schists in the Iwakuni district, Southwestern Japan, which were collected in the outer zone of the banded gneiss zone, shows higher concentration and rhombic symmetry (fig. 65). Whereas the quartz diagram of the banded gneisses proper does not show any characteristic pattern or symmetry. Quartz grains of siliceous banded gneiss are far greater in grain-size than those of biotite-schist, and sillimanite and cordierite are often contained. Therfore, it seems that the quartz grains in the siliceous banded gneiss were formed under the condition of static thermal metamorphism, the effect of shearing being subordinate. The quartz fabric of granitized banded gneisses which shows characteristic pattern and symmetry suggests that quartz has been formed under plastic or viscous condition accompamed by shearing stress.

According to the preferred orientation of quartz of the Gamano and the Okiura masses, which represent the main phase of the Ryôké plutonic activity, they are believed to have been intruded when the regional deformation was still active.

2. *Biotite fabric*

a. In the siliceous banded gneiss with foliation, poles of biotite are remarkably concentrated near the fabric axis *c*, that is, the biotite diagrams conform to the megascopic foliation structure, showing partial girdle. The preferred orientation of biotite is strongest in banded gneiss proper, and as the granitization advances from granitized banded gneiss to gneissic granodiorite, the poles tend to be more dispersed along *ac* plane. The width of the girdle increases as maximum value of concentration decreases, but no complete girdle is formed. The change of concentration of biotite in the fabric diagram from the banded gneisses proper to the gneissic granodiorite is to be correlated to the state of formation of these rock types, *i. e.*, the degree of granitization, increase in plasticity or viscosity, or presumably increase in mobility of the rock during the deformation.

In some samples the position of main maximum is inclined a few degrees to *c*, that being probably interpreted as showing the internal rotation caused by shearing.

b. The fabric pattern of a folded specimen shown in figs. 34 to 36 is characterized by complete girdle with a prominent maximum corresponding to the visible bedding foliation. While, as stated above, the quartz fabric depends on the axial plane, the biotite orientation mainly determined by the original bedding S_1. This contrast suggests that the quartz and the mica fabrics have developed independently with each other during different phases of deformation, *i. e.*, the former was developed later than the latter, except for one of submaxima of the biotite fabric diagram, which may correspond to the same phase of mineralization of quartz. Therefore, the quartz fabric is non-unrollable, while the biotite fabric is unrollable, in other words, the former is post-folding or synfolding, the latter is pre-folding.

c. Some biotite diagrams show submaxima on the *ac* girdle. In thin section there is shown a tendency of biotite blades in biotite-rich band to lie perpendicular to *c*. while scattered grains of biotite in quartzose matrix tend to be oriented perpendicular to the submaximum.

Gault (1945) reported that the mica girdle fabrics of the Pinkeville quartz diorite complex may have been developed as cylindrical flow or as rotation, and that mica flakes orientated in the stream will align themselves with their longest dimension parallel to and their shortest dimension normal to the direction of flow. In the region of the present paper, however, the distinct lineation of the older migmatitic granodiorites, defined by the parallel arrangement of biotite flakes, has generally a gentle plunge and is parallel to that of the banded gneisses. Therefore, the biotite fabrics may be interpreted as developed as a result of shear movement under plastic or viscous state of migmatization. The foliation in the strikingly foliated, but not lineated, older gneissic granodiorites (the Gamano mass) may have been developed as a combined result of shear movement and flow movement prior to solidification.

3. *Plagioclase fabric*

The fabric diagrams of plagioclase (albite-twin lamellae) of the gneissic granodiorites show the striking maximum at *c*, accompanied with partial *ac* girdle. Therefore, the fabric pattern of plagioclase resembles that of biotite. As the foliation and lineation in gneissic granodiorites become obscure, the preferred orientation of plagioclase tends to be disturbed. In the older gneissic granodiorites the twinning type of plagioclase belongs to the metamorphic type according to GORAI's classification. As KISAKI (1957) discussed on the migmatite of the Hidaka, Hokkaido, albite twinning plane of plagioclase of the granodiorites in this region may also be arranged parallel to the plane of movement under shearing condition.

VI CONCLUSION

The formation of banded gneisses derived from the palaeozoic sediments and basic rocks is characterized by the intense thermal-metamorphism accompanied by the effect of shearing:— the occurrence of cordierite and sillimanite in the pelitic and siliceous banded gneisses suggests the predominance of thermal effect. KOJIMA (1953) reported that the Ryôké metamorphism is not the type of normal regional metamorphism but the metamorphism is characterized by intense thermal and material additions to the zone of intense plutonism.

Megascopically foliation and lineation are always well developed in all rock types. The banded structures or the compositional banding should generally regarded as inherit the bedding structure accentuated by metamorphism in the siliceous banded gneiss, and by metamorphic differentiation accompanied by shearing in the pelitic banded gneiss. The foliation surface was intensely folded. Although the folds vary in intensity and scale throughout the region, the type of such folds is the concentric shear folding according to DE SITTER (1956). The earliest phase of metamorphism in the region was represented by the folding of sediments by the compression with the east-west axes of fold.

The fracture and shear cleavage was developed. In less competent pelitic rocks the foliation coincides with the shear plane, but in more competent siliceous rocks no shear plane is megascopically observed. The axial plane of fold and the planar foliation are parallel to the shear plane. The lineation is *b*-lineation and parallel to the fold axis B. There is no other type of lineation due to the intersection of foliation and cleavage, except for a few samples.

The microfabrics of quartz of the siliceous banded gneisses do not show strong concentration or any definable patterns, that suggesting the recrystallization of the mineral under the condition of thermal metamorphism, with no significant effect of shearing. Biotite fabric diagrams show remarkable parallelism of biotite flakes with the megascopic foliation.

In the greater part of the region, particularly in the central area, banded gneisses have suffered granitization and migmatization. The granitization of the banded gneisses is petrographically characterized by feldspathization accompanied by alkali allumina metasomatism. These materials must have been derived from deep-seated granitic magma. The passage from banded gneisses to gneissic granodiorites is observed. It is concluded that the granitization of the banded gneisses by the granitic magma is characterized by the metasomatic addition of alkali and alumina and the subtraction of silica.

The granitized banded gneisses are also intensely deformed, and structural elements such as foliation and lineation are well developed. As both megascopic and microscopic observations reveal no evidences of overlapping structural features due to different phases of deformations, so the granitization may have been contemporaneous with the regional deformation.

The fabric diagrams of biotite show dispersed pattern and the *ac*-girdle is more clearly developed than in the banded gneisses, while those of quartz show higher concentration and symmetry than in the banded gneisses proper.

Evidences concerning the origin of the older gneissic granodiorites so far discussed are summarized below:

The Ôbatake gneissic granodiorite

1) Perfect gradation from the granitized banded gneisses to the gneissic granodiorites can be seen in the field, and migmatitic features are well developed in many places. Most of the contacts between these two rock types are gradational; the rocks pass gradually into each other along and across the strike. Many inclusions in the granitized banded gneisses and the basic rocks occur conformably in the gneissic granodiorites. In many places the Ôbatake gneissic granodiorite has nebulitic structure, that suggesting the origin of the rock as granitized from sediments.

2) The rock is highly variable in composition and is heterogeneous. The rock consists chiefly of quartz, plagioclase, biotite and a small amount of potash-feldspar, usually orthoclase, and rarely microperthite. Sillimānite and cordierite are relatively abundant in places in the Ôbatake mass that lies near the granitized sillimanite-cordierite-bearing banded gneisses. In thin section the texture is granoblastic.

3) The foliation and lineation of both the gneissic granodiorite and the banded gneisses follow the same major and minor stuctural trends.

4) The fabric patterns of biotite are less regular and show less distinct *ac*-girdle than those of banded gneisses. The quartz fabric pattern shows high concentration and approximately rhombic symmetry. Quartz maxima lie near the IV position.

In conclusion, the Ôbatake gneissic granodiorite originated through the processes of *in situ* granitization and migmatization of the banded gneisses.

It is noteworthy that as the granitization from banded gneisses to gneissic granodiorites (Ôbatake) advances the fabric diagrams of quartz exhibit higher concentration and symmetry; while biotite diagrams tend to show less distinct girdle patterns. The fabric diagrams of quartz and biotite of granitized banded gneisses and granodiorites commonly show girdles normal to the lineation as in most of tectonites. The orientation of quartz in the Ôbatake gneissic granodiorite is interpreted as developed by shearing under the condition of increasing viscousity and plasticity, but not under that of fluid flow. The change of biotite orientation also agrees with the successive change of granitization.

The Gokenya gneissic granodiorite

In the Gokenya gneissic granodiorite can be found many features showing its derivation from basic igneous rocks through the processes of granitization. The rock consists chiefly of quartz, plagioclase and biotite accompanied by relatively abundant sphene as an accessory mineral. Calcic plagioclase twinned after the carlsbad law represents a relict of original rocks. Intensely foliated and lineated structures are developed. Trondhjemitic lenses or pools are formed in more advanced stage of granitization.

Markedly pronounced preferred orientation of biotite which is parallel to the megascopic foliation and the microfabric of quartz showing strong concentration and rhombic symmetry are attributed to the recrystallization under the condition of shearing.

The Gamano and Okiura gneissic granodiorite

The rocks are characterized by both igneous and metamorphic features, that indicating their syntectonic origin, *i. e.*, the formation during the folding and metamorphism of the region.

Several facts pointing out the metamorphic origin of the rocks may be enumerated. The granitized banded gneisses often pass gradually into the gneissic granodiorite, forming the migmatite as well as the Ôbatake mass. Highly variable features and compositions of the rocks and the metamorphic texture under the microscope indicate the migmatitic origin. The masses include layer-or schlieren-formed relicts of banded gneisses and basic rocks. The foliation and lineation of these relicts are parallel to those of the adjacent enclosing gneissic granodiorites. Basic inclusions also suffered granitization, forminghy brid facies between the former and the gneissic granodiorites.

The Gamano and Okiura gneissic granodiorites have sharp, apparently intrusive contact with the banded gneisses in the east and west margin of the region, and the gneissosity is lacking in places.

From the lack of a contact effect normally found around igneous masses it can be inferred that the older granodiorites was completely harmonic with the banded gneisses with respect to the mineral facies which is characterized by the assemblage of sillimanite, garnet and cordierite.

Such features as stated above of the Gamano and Okiura gneissic granodiorite suggest its origin of regional metamorphism, while there are other features suggesting igneous flowage.

The microfabric of mica is less regular than that of the Ôbatake gneissic granodiorite and shows roughly *ac*-girdle. Quartz shows less regular fabric patterns than those of the Ôbatake gneissic granodiorite, and quartz may probably recrystallized later than biotite.

The younger granodiorites comprise four types, the *Tôwa* granodiorite, the *Kibe* granodiorite, the *Murotsu* granite, and the *fine-grained* granodiorite dikes. They are interpreted as crystallized from igneous magma. The evidence for this interpretation is as follows:

The Tôwa granodiorite occurs as a large botholith extensively occupying the south -ern part of the region. The Kibe and the Murotsu granodiorites occur as stocks.

All these masses were intruded quite discordantly to the regional structure. All the younger granodiorites and granites show the igneous texture. There are no evidences to show granitization and migmatization of the banded gneisses and amphibolites.

The history of the Ryôké metamorphism and plutonism of the Yanai district may be summarized as follows:

1) During the late Palaeozoic, siliceous, pelitic and psammitic sediments, intercalated with thin layers or lenses of calcareous sediment and basic rocks, were deposited in the geosyncline (the Chichibu geosyncline).

2) Early in the Mesozoic, the sediments were metamorphosed by the igneous activity accompanied by the contemporaneous orogenic folding with axes striking east-west, and the following three metamorphic zones were resulted; *i. e.*, the outer zone (non-metamorphic rocks), the biotite schist zone and the banded gneiss zone. The banded gneiss zone represents the most extended stage of metamorphism.

3) Succeeding the regional metamorphism, the granitization and migmatization caught the rocks of the banded gneiss zone, locally resulting in the formation of the autochthonous-migmatitic granodiorites (Ôbatake, Gokenya).

4) The formation of migmatitic, gneissose granodiorites was closely followed uppon by the intrusion of magma which represents the main phase of ingeous activity of the region, producing parautochthonous migmatite in places during the orogenesis (Gamano, Okiura).

5) After the older igneous activity was over, several younger granodiorites were intruded.

The Ryôké granodioritic complex exhibits features corresponding to various stages of the granite series (READ 1950).

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Explanation of Plate XVI

True scale photographs of representative hand specimens.

Fig. 1. Pelitic banded gneiss, coast from Himi to Yokomi, Ôshima. Quartzose layers and lenses occur parallel or subparallel to the foliation, suggesting that the foliation has been produced from bedding by transposition. Perpendicular to the lineation.

Fig. 2. Granitized pelitic banded gneiss, Befu, Marifu. Specimen no. 58021501. Perpendicular to the lineation.

Fig. 3. Granitized siliceous banded gneiss, coast from Himi to Yokomi, Ôshima. Perpendicular to the lineation.

Fig. 4. Ôbatake gneissic granodiorite (Sakagawa type), Sakagawa, Hizumi. Perpendicular to the lineation.

Fig. 5. Ôbatake gneissic granodiorite (Ôkubo type), Ôkubo, Ôbatake. Perpendicular to the foliation.

Fig. 6. Gokenya gneissic granodiorite, Gokenya, Hikari City. Perpendicular to the lineation.

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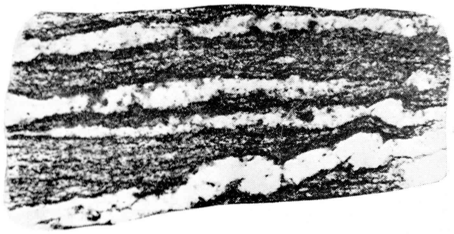

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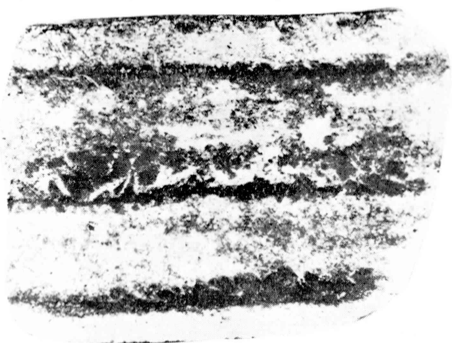

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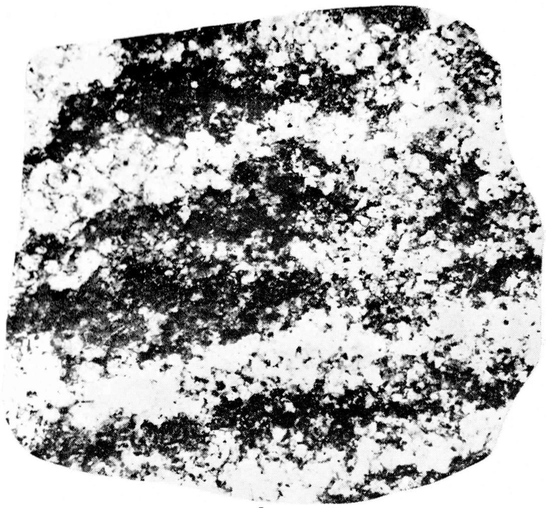

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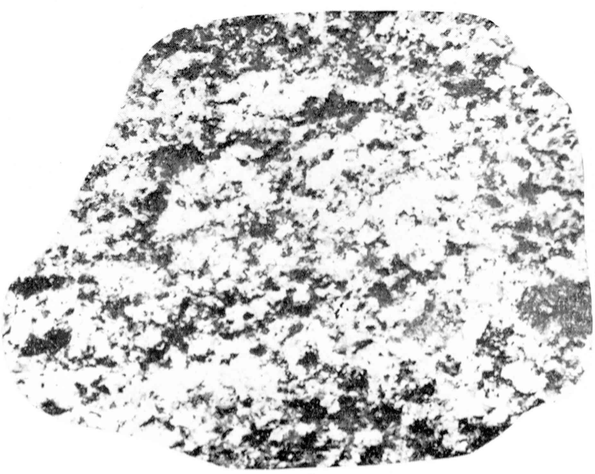

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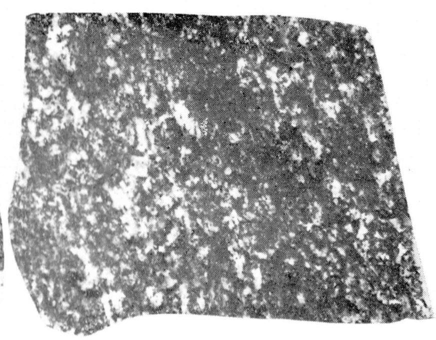


6

Explanation of Plate XVII

True scale photographs of representative hand specimens.

Fig. 1. Ôbatake gneissic granodiorite, Tana. The upper part is the nebulite of pelitic banded gneiss.

Fig. 2. Gamano gneissic granodiorite, coast from Mukuno to Migama, Ôshima. Perpendicular to the foliation.

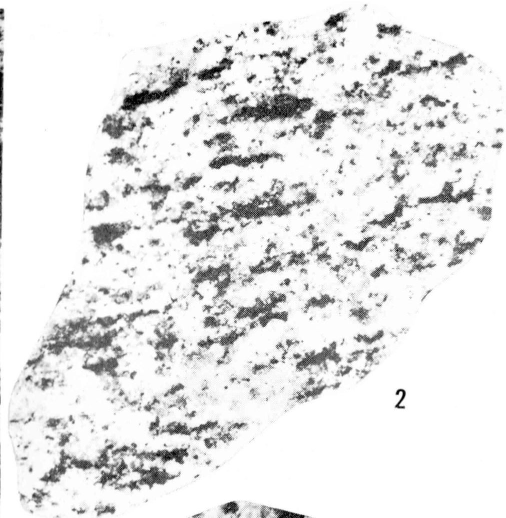
Fig. 3. Okiura gneissic granodiorite, coast from Heta to Yokomi, Ôshima.

Fig. 4. Towa granodiorite, Nagasaki, Kuga Town, Ôshima.

Fig. 5. Kibe granodiorite, Utsugiyabu, Hizumi.

Fig. 6. Murotsu granite, Okumage, Murotsu.

1



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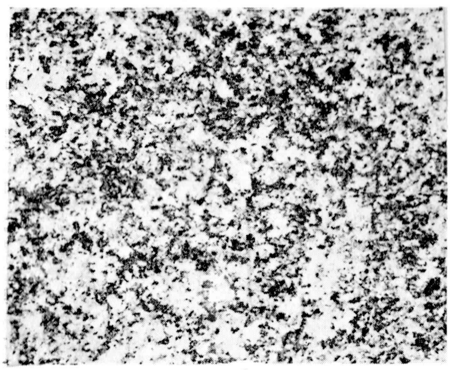

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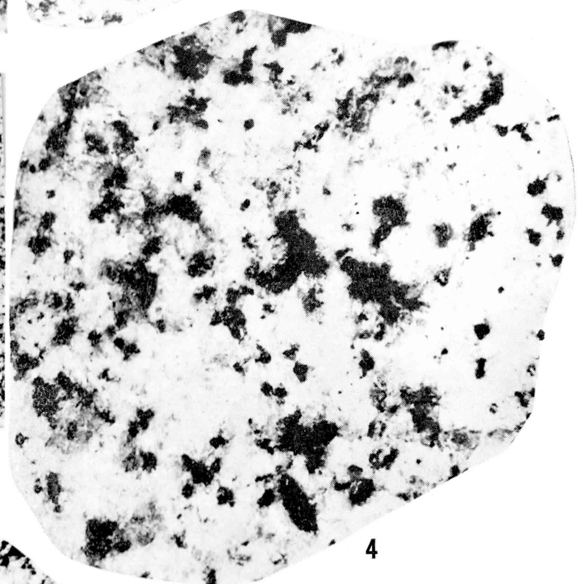

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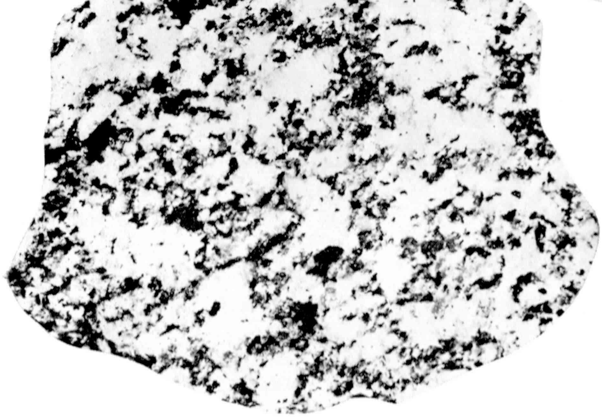

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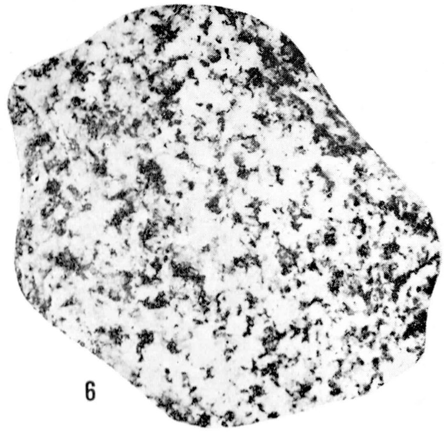

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Explanation of Plate XVIII

Field occurrence

Fig. 1. Granitized siliceous banded gneiss, coast of Himi, Ôshima. Folded structure of siliceous banded gneiss is well preserved, but the rock is now granodiorite.

Fig. 2. Migmatitic facies of the Gamano gneissic granodiorite, coast from Munemitsu to Mukuno.

Fig. 3. Migmatitic facies of the Okiura gneissic granodiorite, coast from Heta to Yokomi. (G) granodiorite, (P) pelitic banded gneiss, (S) siliceous banded gneiss.

Fig. 4. Migmatitic facies of the Gamano gneissic granodiorite, showing nebulite of siliceous banded gneiss (S), Befu, Tabuse Town.

Fig. 5. Contact relation between the Gamano gneissic granodiorite and banded gneiss, coast from Mukuno to Migama, Ôshima. (MG) medium-grained gneissic granodiorite, (CG) coarse-grained gneissic granodiorite, (P) pelitic banded gneiss.

Fig. 6. Contact relation between the Gamano gneissic granodiorite and banded gneiss, Wakasugi, Hizumi. The granodiorite exhibits migmatitic features. (P) pelitic banded gneiss, (A) aplite, (G) granodiorite.


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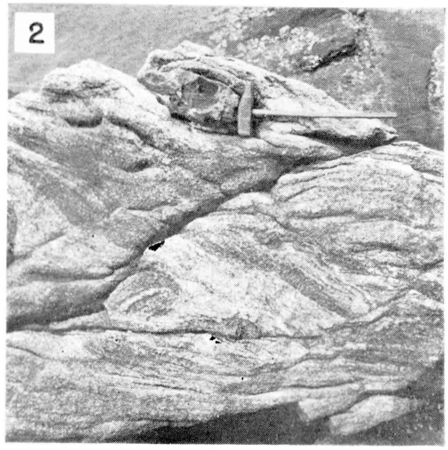
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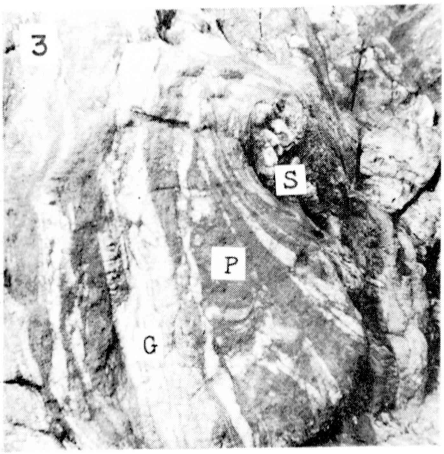
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P
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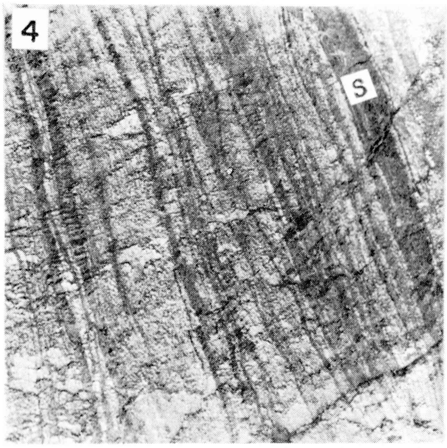
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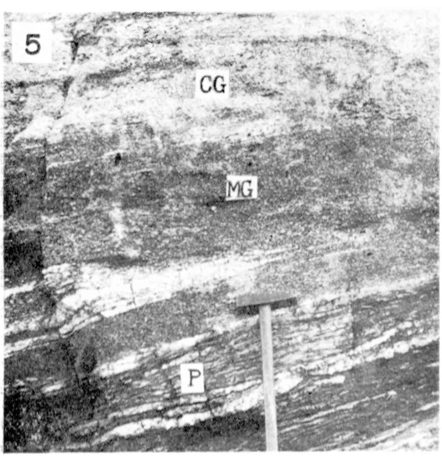
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CG
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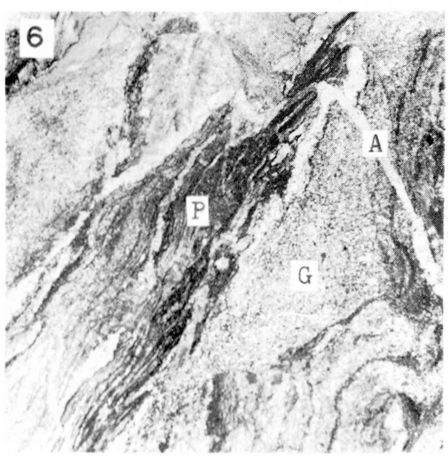
6
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Explanation of Plate XIX

Field Occurrence.

Fig. 1. Contact between the Gamano gneissic granodiorite and the pelitic banded gneiss, Kandori Cape, Hikari City. The gneissic granodiorite cut discordantly the pelitic banded gneiss, but the foliation of the granodiorite is parallel to the foliation of the pelitic banded gneiss.

Fig. 2. Basic inclusions in the Gamano gneissic granodiorite, coast from Komatsu to Migama, Ôshima.

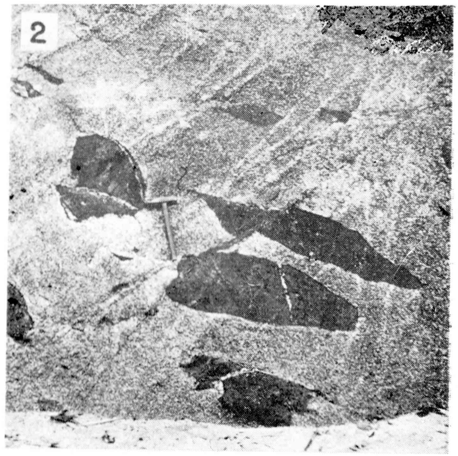
Fig. 3. Granitization of basic rocks, coast from Mukuno to Migama, Ôshima. (G) granodiorite, (D) meta-diabase, (A) aplite.

Fig. 4. Granitization of basic rocks, coast from Mukuno to Migama, Ôshima. Trondhjemitic network veins are well developed.

Fig. 5. Granitization of basic rocks, Johonan, Tabuse Town. Amphibolite is gradually changed to medium-grained biotite granodiorite (hybrid rock). (A) amphibolite, (G) medium-grained biotite granodiorite, (P) pegmatite.

Fig. 6. Pegmatite and aplite cutting siliceous banded gneiss, Katano, Yanai. (P) pegmatite, (A) aplite, (S) siliceous banded gneiss.


1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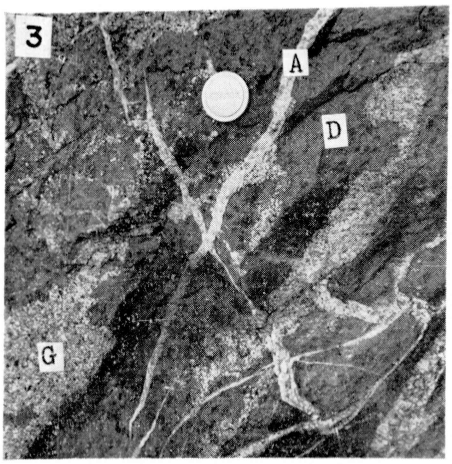
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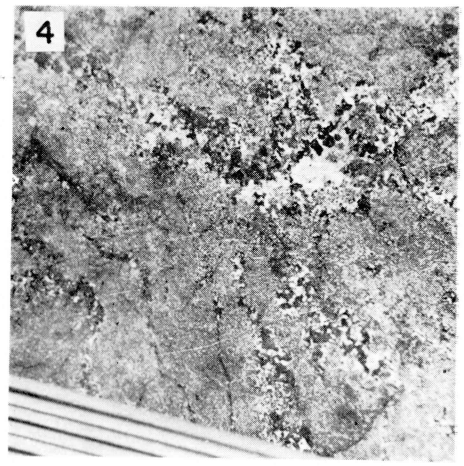
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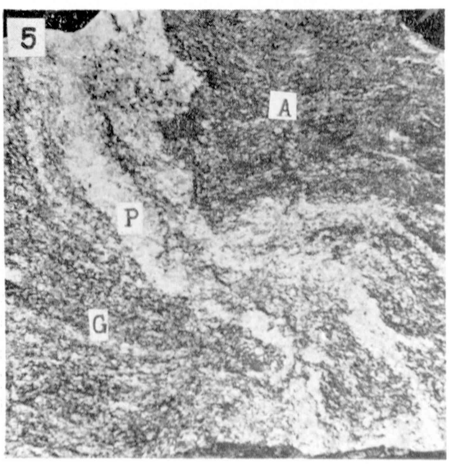
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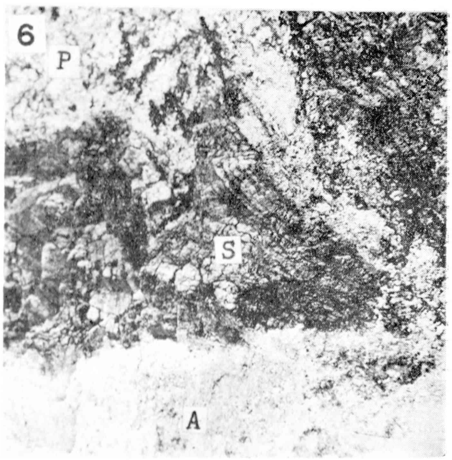
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P
S
A

Explanation of Plate XX

Microphotograph.

Fig. 1. Pelitic banded gneiss, Morigatao, Mitsui, Hikari City. The constituents, in the order of abundance, are plagioclase, quartz, biotite and sillimanite. Lower nicol only. ×25.

Fig. 2. Siliceous banded gneiss. The constituents are quartz, biotite and cordierite (C). Chausuyama, Yanai City (Specimen no. 57110306). Crossed nicols. ×25.

Fig. 3. Ôbatake gneissic granodiorite (Sakagawa type), Sakagawa, Hizumi. The rock consists of plagioclase, Orthoclase, quartz, cordierite, biotite, muscovite and sillimanite. Crossed nicols. ×10.

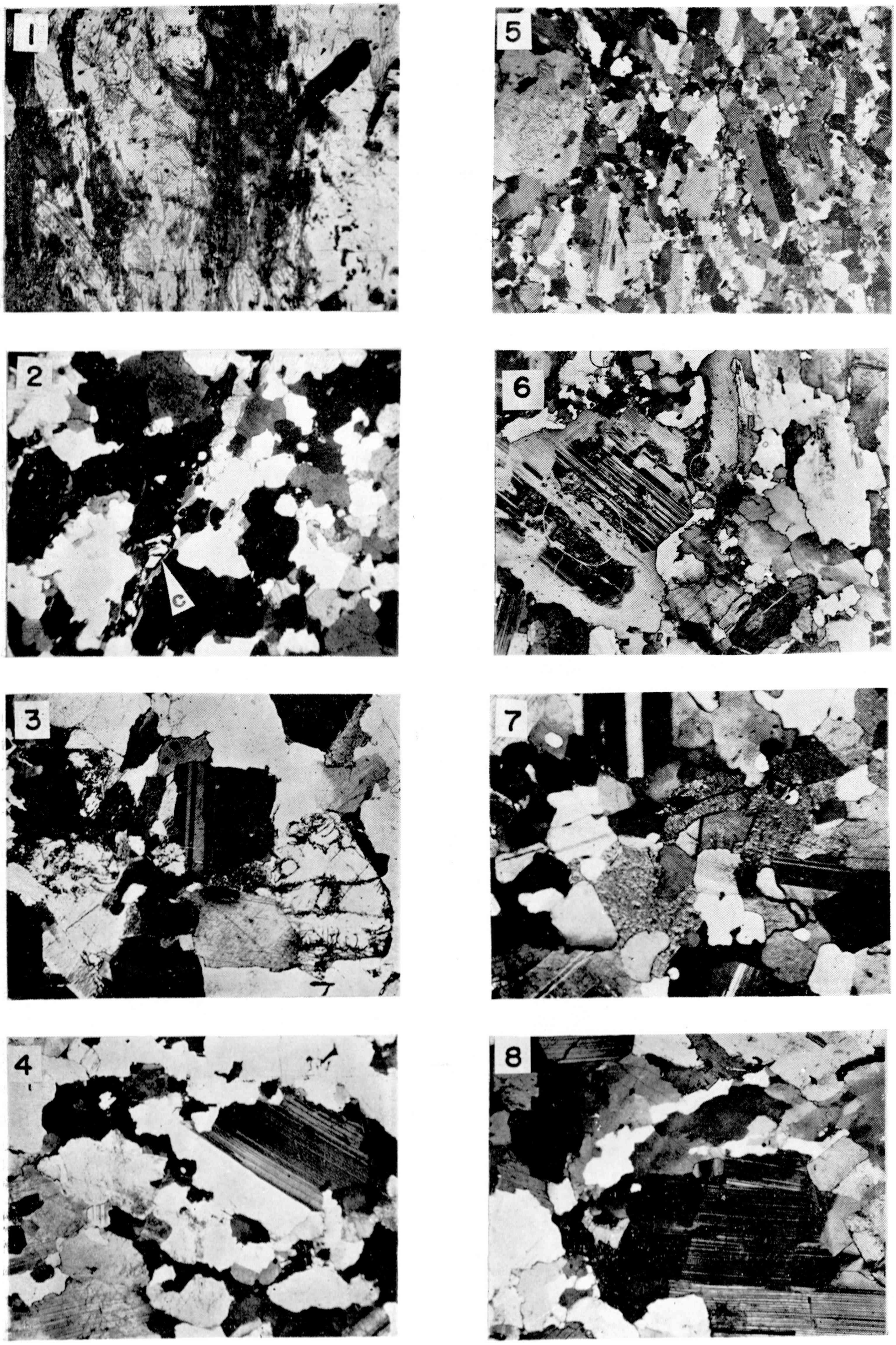
Fig. 4. Ôbatake gneissic granodiorite (Ôkubo type), Ôkubo, Ôbatake. Biotite, quartz, and plagioclase. Crossed nicals. ×10.

Fig. 5. Gokenya gneissic granodiorite (Specimen no. 58021502), Gokenya, Hikari City. Quartz, plagioclase, biotite, and sphene. Crossed nicols. ×10.

Fig. 6. Trondhjemitic patch in the Gokenya gneissic granodiorite. Plagioclase, quartz, biotite, and hornblende. Crossed nicols. ×10.

Fig. 7. Gamano gneissic granodiorite (Specimen no. 58050403). Plagioclase, quartz, and biotite. Crossed nicols. ×10.

Fig. 8. Okiura gneissic granodiorite, Heta, Ôshima. Plagioclase, orthoclase, quartz, and biotite. Crossed nicols. ×15.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Explanation of Plate XXI

Microphotograph.

Fig. 1. Metadiabase, Mukuno, Ôshima. Common hornblende, biotite, plagioclase, and quartz. Lower nicol only. ×25.

Fig. 2. Amphibolite, Ihoki, Hikari City. Biotite, common hornblende, plagioclase, and quartz. Lower nicol only. ×25.

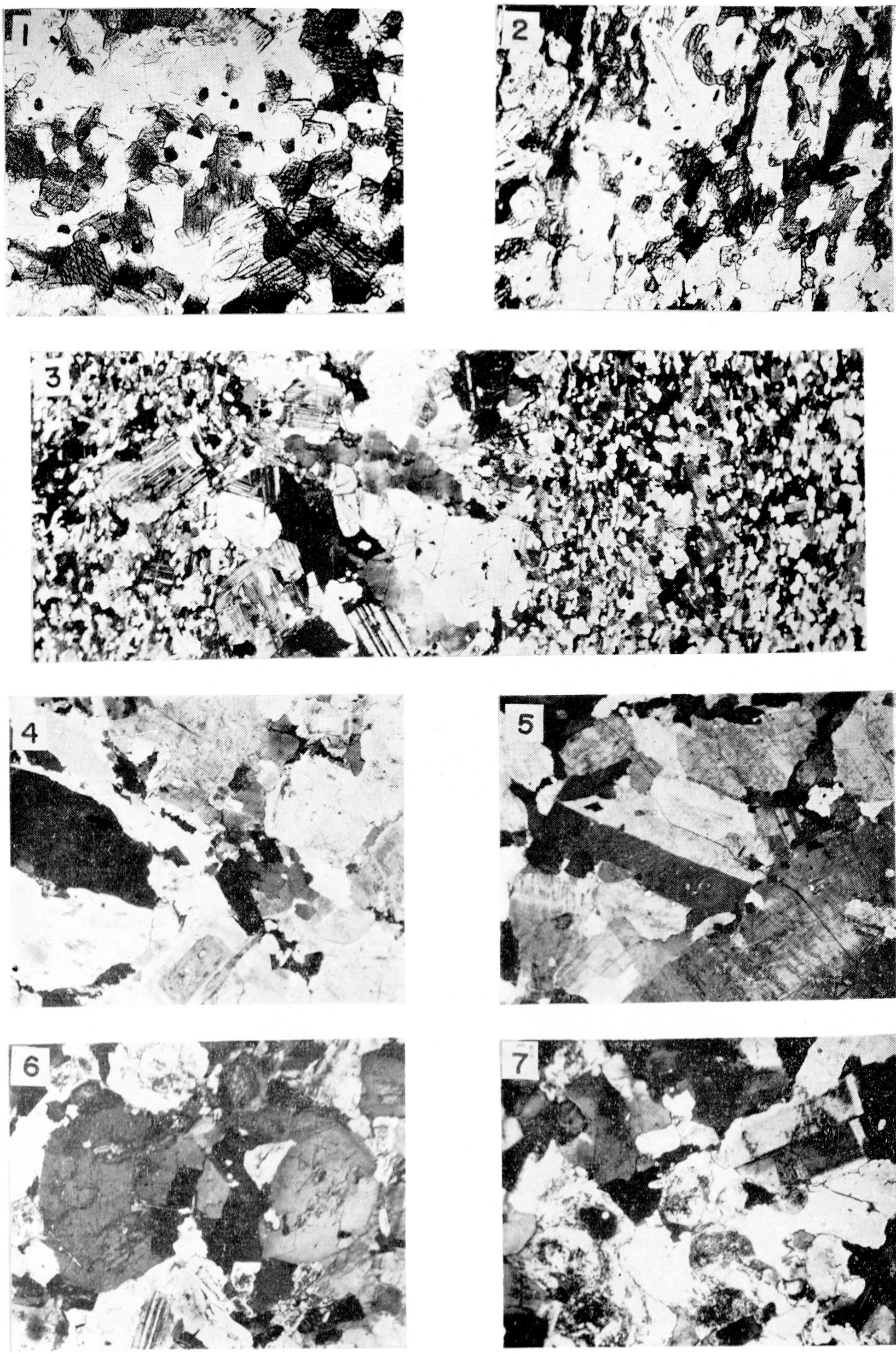
Fig. 3. Network vein in amphibolite, Mukuno, Ôshima. The constituents of vein are hornblende, biotite, quartz and plagioclase. Crossed nicols. ×8.

Fig. 4. Tôwa granodiorite, Shitata, Ôshima. Plagioclase, microcline, quartz, and biotite. Crossed nicols. ×10.

Fig. 5. Kibe granodiorite, Utsugiyabu, Hizumi. Microcline, plagioclase, quartz, and biotite. Crossed nicols. ×10.

Fig. 6. Murotsu granite, Okumage, Murotsu. Orthoclase, plagioclase, quartz, muscovite, and biotite. Crossed nicols. ×10.

Fig. 7. Fine-grained granite, Ihonoshô, Yanai. Plagioclase, orthoclase, quartz, and biotite. Crossed nicols. ×10.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GEOLOGICAL MAP OF THE YANAI DISTRICT