Structural-Petrological Studies of Metamorphic Complex of the Seburi Mountainland, with Special Reference to its Bearing on the Metamorphism of the Sangun Metamorphic Zone in Northern Kyûshû

By

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with 6 Tables, 5 Text-figures, and 4 Plates

ABSTRACT It has long been a theory generally accepted by Japanese geologists that the Sangun metamorphic zone is mainly composed of low-grade metamorphic rocks, and that those higher-grade metamorphic rocks found sporadically in the zone were formed by thermal effect of either older or younger granite.

The writer was interested in the presence of higher-grade metamorphic rocks in the Seburi mountainland, which belongs to the Sangun metamorphic zone, and thenceforth attempted to solve a problem as to whether the higher-grade metamorphic rocks which attain to the amphibolite facies in metamorphic grade were formed by the thermal effect of granite or by the dynamo-thermal metamorphism. In an attempt to find a solution to this problem, the writer began in the present paper by giving the outline of the basement geology of Northern Kyûshû as the geological background of the Seburi district, and proceeded to discuss the geology and petrology of the district, with particular reference to the mineral-paragenetic relation and petrofabric analysis.

With regard to the genesis of minerals, especially of garnet, epidote, tourmaline and cummingtonite, the writer has discussed from the standpoint of the mode of occurrence, and the genesis of biotite and amphibole has been dealt with from the viewpoint of petrofabrics. From the results the writer has drawn the conclusion that garnet, epidote, tourmaline, and cummingtonite were formed by the thermal effect of older granite and the greater part of biotite and amphibole by the preceding dynamo-thermal metamorphism. Therefore, these metamorphic rocks referred to the amphibolite facies were formed not by the thermal effect of older granite, but by the dynamo-thermal metamorphism.

In addition the writer has discussed at some length the geological significance of the above conclusion in the basement geology of Northern Kyûshû.

CONTENTS

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I INTRODUCTION

The Sangun metamorphic rocks are generally believed by geologists to be rocks of low-grade regional type of metamorphism, belonging mainly to the chlorite zone. In the Seburi Mountainland, Fukuoka Prefecture, however, the existence of higher-grade metamorphic rocks such as plagioclase-amphibolites and biotite-quartz-schists have long been known. As seen in the geological map they are closely associated with the older granitic intrusion named the "older granites of Northern Kyûshû" (the Itoshima type) by T. MATSUMOTO (1951). Therefore, they have once been interpreted by the present writer and G. KOJIMA (1947) and also by T. MATSUMOTO (1951) as derived from the low-grade crystalline schists of the Sangun metamorphic zone under the thermal effect related to the older granitic intrusion.

The writer (1959) found as a result of petrofabric analysis that a part of crystalline schists in the Chikugo Mountainland, situated to the south of Kurume, Fukuoka Pref., belongs to the biotite zone of regional metamorphism. In these several years the writer has attempted petrofabric analysis of rocks of the Seburi district with the intention of determining whether the higher-grade metamorphic rocks were formed by the Sangun metamorphism of dynamo-thermal type or by the granitic intrusion after the Sangun metamorphism. On the basis of the petrofabric analysis, it has been revealed that the metamorphic rocks in the Seburi district had already evolved into the state of amphibolite facies of dynamo-thermal type of metamorphism before the emplacement of the older granite. In this paper the writer intends to describe petrographical properties and petrofabric characteristics of crystalline schists in the district, and along with this, to give the outline of the basement geology of Northern Kyûshû as the geological background of the district, with special reference to the significance of the result of study in the district.

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II OUTLINE OF GEOLOGY OF THE METAMORPHIC BASEMENT OF NORTHERN KYÛSHÛ

(mainly, the Asakura, Chikugo, and Sasaguri districts)

The basement older formation of Northern Kyûshû is composed of Palaeozoic rocks and their metamorphic equivalents. According to T. MATSUMOTO (1951), the basement formation of Northern Kyûshû and western Chûgoku is divided into the following zones.

1) Northern Metamorphic Zone (Seburi-Sasaguri-Toyogatake-Iwami coastal region)

2) Central Non-Metamorphic Zone
3) Southern Metamorphic Zone (Asakura-Tagawa-Motoyama-Tokuyama)

Since 1950 the writer has been engaged in the geological and petrological researches of metamorphic rocks of Northern Kyûshû, mainly in the Chikugo, Asakura, and Seburi districts. Metamorphic rocks in the Sasaguri district of the Sangun Mountainland, east of Fukuoka, were studied by H. MAIKUMA (1959).

The distribution and general geologic structure of the Basement formation of Northern Kyûshû are shown in fig. 1. In the following the outline of geology and petrology of crystalline schists in the Chikugo, Asakura and Sasaguri districts will be described.

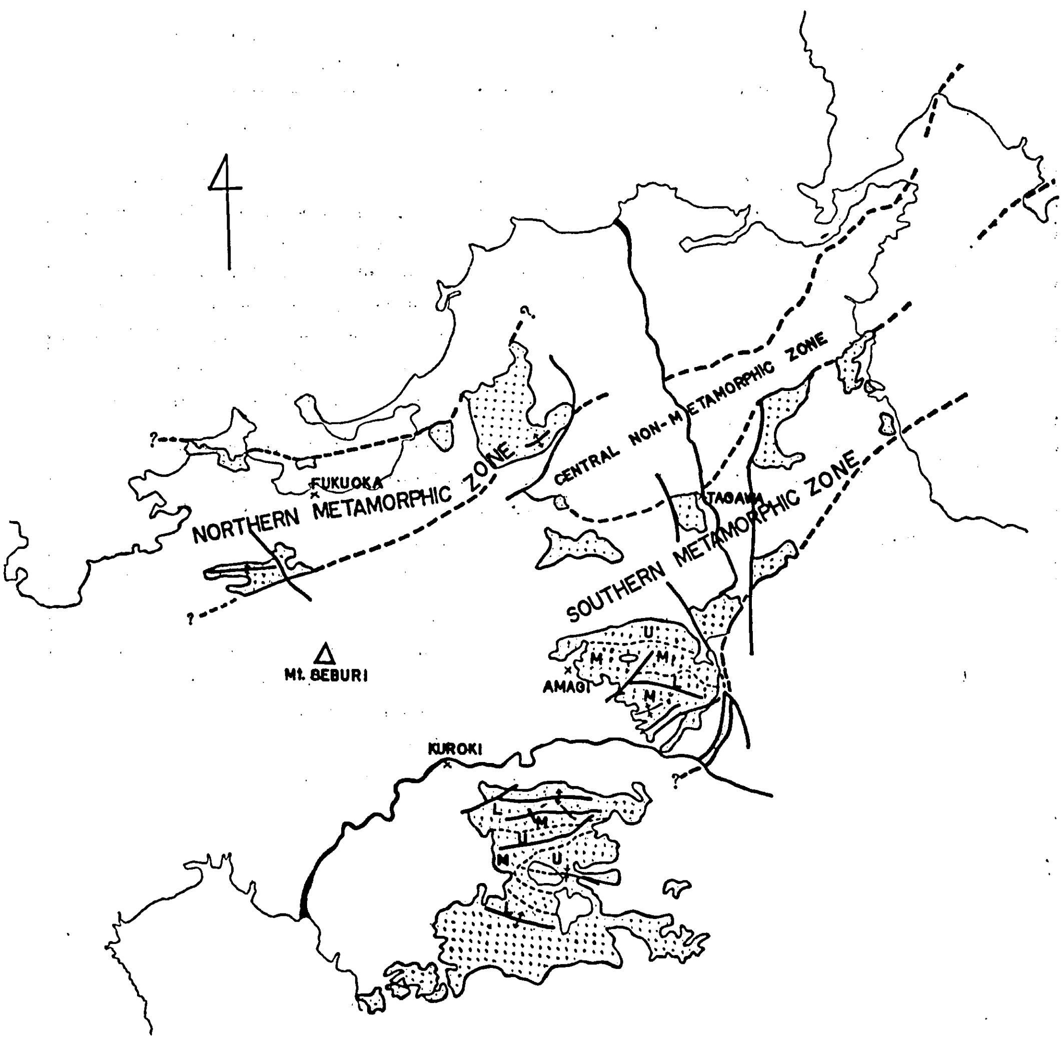

FIG. 1. Geologic structure and distribution of crystalline schists in Northern Kyûshû. L, M, and U represent the lower, middle, and upper formation respectively.

A Stratigraphy

As the Chikugo district is separated by the Chikugo alluvial plain from the Southern Metamorphic Zone, direct relation between those matamorphic terrains can not be determined. From the similarity in lithological stratigraphy between the Chikugo district and the Asakura district of the Southern Metamorphic Zone, however, the writer includes the former into the Southern Metamorphic Zone. The lithological stratigraphy in both the Chikugo and the Asakura district is shown in table 1.

Table 1 Stratigraphical Correlation Between the Asakura and the Chikugo Districts, Southern Metamorphic Zone of Northern Kyûshû

Lithological Stratigraphy	the Chikugo District	the Asakura District
Upper Formation	Thickness of the formation 1200 m or more. (the upper limit of the formation is not ascertainable.) Mainly black-schist beds of shale origin. In places, thin quartz-schist and green-schist beds are intercalated.	Thichness of the formation 880 m or more. (The upper limit of the formation is not ascertainable.) Mainly black-schist beds of shale origin. In places, thin and discontinuous sandstone-schist and green-schist beds are intercalated. The uppermost part is characterized by lenticular limestone.
Middle Formation	Thickness of the formation 1200 m. Mainly, thick sandstone-schist and green-schist beds. Thin black-schist, and quartz-schist beds, piedmontite-bearing, are intercalated.	Thickness of the formation 600 m. Mainly, sandstone-schist beds and two conspicuous green-schist beds. Sometimes, thin black-schist beds are intercalated. Green-schist beds are accompanied by thin quartz-schist beds.
Lower Formation	Thickness of the formation 600 m or more. (The lower limit of the formation is not ascertainable.) Mainly, black-schist of shale origin. Sometimes, thin and discontinuous quartz-schist and green-schist beds are intercalated.	Thickness of the formation 800 m or more. (The lower limit of the formation is not ascertainable.) Mainly, black-schist beds of shale origin. Sometimes, thin and discontinuous sandstone-schist beds are intercalated.

The crystalline schists of the Sasaguri district belong to the Northern Metamorphic Zone. In the Sasaguri district crystalline schists, mainly green-schists, are distributed in the northern part, and younger and older ultrabasic and basic intrusives in the southern part. As the Sasaguri district is separated from the Asakura district by granitic intrusives, the stratigraphical correlation between both remains obscured.

B Metamorphism

In the Chikugo district, the greater part of crystalline schists belongs to the chlorite zone, but in the northern part of the district are found rocks containing biotite. Though the crystalline schists of the northern-most part show the thermal effect of younger granitic intrusion (the Sawara type), the existence of crystalline schists which must be referred to the biotite zone of regional metamorphism has been clarified by the writer (1957) by means of petrofabric analysis. The stratigraphical horizon of those crystalline schists belonging to the biotite zone has been correlated to that from the lowermost part of the middle formation to the lower formation.

In the Asakura district, the metamorphic rocks are assigned to the green-schist facies, epidote-amphibolite facies and amphibolite facies from the metamorphic grade. The distribution of metamorphic rocks referred to the amphibolite facies are limited to the northern part near the older granite (the Asakura type) and the stratigraphical horizon of them corresponds to the uppermost part of the upper formation. Metamorphic rocks referred to the epidote-amphibolite facies are found in the central area with a dome-structure, about 3 km away from the boundary of the granite. They are correlated stratigraphically to the middle formation. Metamorphic rocks referred to the biotite-chlorite subfacies of the green-schist facies are also found in this area. Rocks referred to the muscovite-chlorite subfacies are distributed in the southern part, farther away from the granite. They correspond to the middle and upper formation.

Judging from the geological relationship of these metamorphic rocks above described, the writer believes that the metamorphic rocks referred to such higher-grade metamorphic facies as the amphibolite and the epidote-amphibolite facies of the Asakura district were derived from the lower-grade metamorphic rocks under the thermal effect related to the granitic intrusion. The greater part of rocks referred to the biotite-chlorite subfacies can also be believed from the low-grade rocks by the thermal effect of subsequent intrusion of granite. A part of crystalline schists containing biotite, however, is suspected to have been formed under the stress condition of the regional type of metamorphism as proved in the Chikugo district. This problem must be solved by petrofabric analysis in future.

In the Sasaguri district the metamorphic grade of crystalline schists is referred by H. Maikuma to the green-schist and the epidote-amphibolite facies.

From the cursory survey on the metamorphism above noted, it may well be concluded that the greater part of the Sangun crystalline schists of Northern Kyûshû is referred to the chlorite-muscovite subfacies of the regional type of metamorphism, and that a part of them is referable to the biotite-chlorite subfacies and the epidote-amphibolite facies of regional metamorphism, even when the thermal effect of granite is eliminated.

C Structure

In the Chikugo district, the geologic structure is characterized by gentle folds consisting of anticlines with the trend of E-W in the northern and the southern parts and a syncline of ESE-WNW in the central part. Owing to the existence of faults, the original wave-length of fold is difficult to determine, but it is roughly estimated at 12km. The lineation (L_1)[1] which is represented by micro-corrugation on the schistosity (foliation) surface, is generally parallel to the regional fold axis (B), but in the cenral part, corresponding to the middle formation, another type of lineation (L_2), also represented by micro-corrugation, intersecting at about right angles to the lineation L_1, is found. From the results of geometrical and petrofabric analyses, it is concluded that the lineation L_2 was formed at the same time with the lineation L_1 (INOUE, 1959).

In the Asakura district, a dome-structure is shown in the central part and an anticrinorium trending E-W is found in the southern part. As in the case of the Chikugo district, the geologic structure is characterized by gentle folds. The lineation (L_2) trending NE-SW to NNE-SSW can be observed throughout the area except near the vicinity of granite, where the lineation is obscured. But in the southern part, corresponding to the zone of muscovite-chlorite subfacies, the lineation (L_1) intersecting the lineation L_2 at about right angles can be found. The lineation L_1 is parallel to the regional fold axis (B_1), while the lineation L_2 is parallel to the fold axis (B_2) on a small scale. From the results of geometrical analyses, it can be concluded that the lineation L_1 antedated the lineation L_2 in the Asakura district (INOUE, 1960).

In the Sasaguri district, the geologic structure is also characterized by gentle folds, and the lineations L_1 and L_2 intersect with each other at about right angles. One of them is parallel to the regional fold axis.

D CRITICAL COMPARISON BETWEEN THE SOUTHERN AND THE NORTHERN METAMORPHIC ZONES.

Based on the above description, a critical comparison between the Southern and the Northern Metamorphic Zone is attempted as follows.

i) The schist complex of the Southern Metamorphic Zone is divided stratigraphically into three formations, in which green-schists predominate in the middle formation. On the other hand, the schist complex of the Northern Metamorphic Zone is mostly composed of green-schists. The stratigraphical relation between the Southern and the Northern Metamorphic Zone can not directly determined. If these schist complexes of both zones can be unified into single stratigraphic succession, however, the green-schist formation of the Northern Metamorphic Zone may be correlated to the middle formation of the Southern Metamorphic Zone.

ii) The characteristic features of geologic structure which are common for both zones are the gentle folds and the presence of two lineations (L_1 and L_2) intersecting with each other at about right angles.

iii) It has long been believed among geologists that in the Sangun Metamorphic Zone no higher-grade crystalline schists of regional metamorphic type exist, and that higher-grade metamorphic rocks are derived from schists of the muscovite-chlorite subfacies by the thermal effect of subsequent granitic intrusion, but crystalline

1) In this paper, the lineation parallel to the regional fold axis (B) is designated as L_1 and that intersecting L_1 at about right angles as L_2. Generally, as the regional fold axis has the trend of E-W, in the districts now in consideration L_1 tends to trend E-W, and L_2 N-S.

schists higher than the biotite-chlorite subfacies were confirmed in both zones.

As mentioned above two metamorphic zones show common features, but there exist differences between them as noted below.

i) In the Northern Metamorphic Zone green-schists are more predominating than in the Southern Metamorphic Zone.

ii) As for the intrusive rocks, the occurrence of both younger and older synkinematic ultrabasic and basic rocks is characteristic in the Northern Metamorphic Zone.

iii) As for the grade of metamorphism of synkinematic type, that of the Northern Metamorphic Zone is higher than that of the Southern Metamorphic Zone, especially in the Seburi district it attains to the amphibolite facies.

iv) In the Southern Metamorphic Zone crystalline limestone has not been found in the green-schist formation, while in the Northern Metamorphic Zone limestone is fairly abundant in the green-schists.

III Metamorphic Rocks of the Seburi District.

In the following will be discussed geological and petrological features of metamorphic rocks of the Seburi district, which have bearing on the problem of geology and petrology of the Sangun Metamorphic Zone of Northen Kyûshû.

A Geological Setting

The metamorphic complex of the Seburi Mountainland about 20 km west of the Sasaguri district, the Sangun Mountainland, is generally regarded as a western extension of the Sangun Metamorphic Zone. The metamorphic rocks are composed mainly of plagioclase-amphibolites and biotite-quartz-schists, the complex being enclosed by older and younger granites (the Itoshima type, the Kaho type, and the Sawara type). In the southern part of the complex ultrabasic and basic rocks such as peridotite and meta-gabbro are distributed. The general trend of bedding-schistosity plane is *E-W* and its dip inclines at high angles towards *N* or S. The general trend and distribution of ultrabasic and basic rocks in this district is analogous to those of the Sasaguri district, but as for features of metamorpism the former differs from the latter.

B Geologic Structure

The metamorphic complex of the district is bounded on the north by an intrusive of granodiorite called the older granite of Northern Kyûshû (the Itoshima type), while the southern boundary is not determined directly by the field evidence, but it can be regarded as a fault trending E—W, which is evidenced by the petrofabric analysis of limestone collected in the vicinity of the boundary. A younger biotite granite (the Kaho type) is distributed to the south of the fault.

c-Axis of calcite is measured for 100 grains with the result shown in fig. 2. As calcite is a sensitive mineral to the thermal effect, the fabric diagram of calcite should show high dispersion of *c*-axes, if limestone were affected by the thermal metamorphism. This fabric pattern of the mineral, however, shows distinct concentration. This fact shows that the limestone were not affected by the thermal effect related to the younger granite. Therefore, it is clear that the metamorphic complex and the younger granite are bordered by a fault.

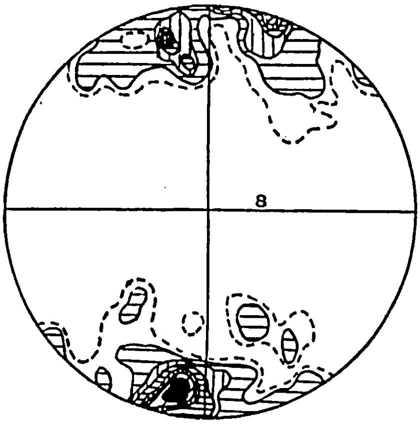

Fig. 2a. 100 c-axes of calcite from crystalline limestone of Mizunashi (No. 11306). Contours: 7-6-5-4-3-2-1 %.

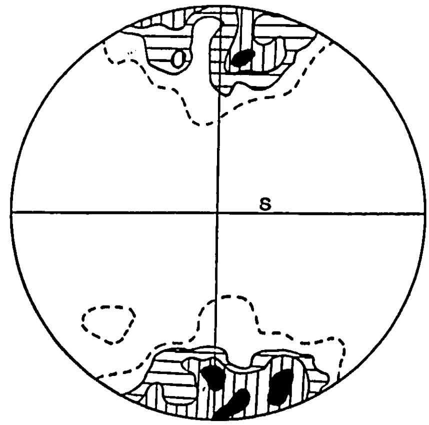

Fig. 2b. 80 poles of e-lamellae of calcite from crystalline limestone of Mizunashi (No. 11306). Contours: 5-3.8-2.5-1.3%.

Another fault which is evidenced by the presence of mylonite runs NW-SE in the eastern part of the complex. To the east of the fault is exposed another younger granite, which is muscovite-biotite granite (the Sawara type). The thermal effect related to the granite is weak, but the metasomatic effect is strong, as evidenced in limestone.

At Nishiyama limestone enclosed in the granite has many skarn minerals such as diopside, vesuvianite, tremolite, epidote, garnet etc., while biotite-quartz-schists which are collected in the proximity of the limestone show the same petrofabric patterns of quartz and biotite as those in Subarea Ib, namely, the quartz fabric pattern is the type f after H. W. Fairbairn (1949) and the biotite fabric pattern shows a slight dispersion. This fact indicates that the metamorphic rocks of the eastern part have not received any thermal effect, but some metasomatic effect.

Therefore, two younger granites (the Sawara type and the Kaho type) of the district did not play any important role in the formation of metamorphic rocks. On the other hand, the older granite (the Itoshima type) to the north gave distinct thermal effect and added materials to the metamorphic rocks. The older granite penetrates the metamorphic complex concordantly or subconcordantly, and it has foliation which is nearly parallel to the boundary between the granite and the metamorphic complex.

The geological structure of the metamorphic complex is in general simple and the geometrical characters of structural elements are rather homogeneous throughout the complex. In the northern part a syncline with nearly vertical, E-W trending axial plane exists.

The general trend of bedding-schistosity plane is E–W and the dip is N or S at high angles, while the lineation whithin bedding-schistosity plane plunges at low angles towards ENE or WNW.

The principal maximum in the lineation diagram lies in the second quadrant, in

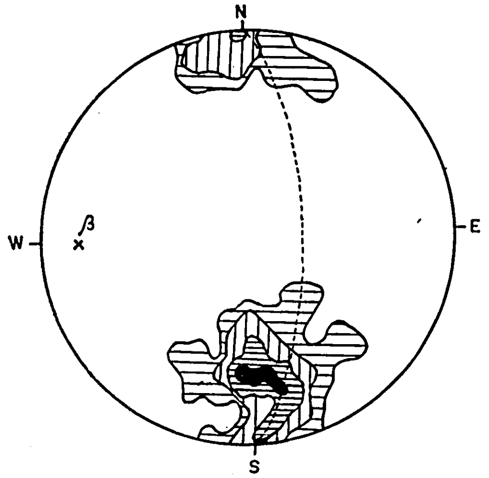

FIG. 3a. π-diagram of bedding-schistosity plane in the whole area. Measurements: 52. Contours: 15.1-11.5-5.6-1.8%

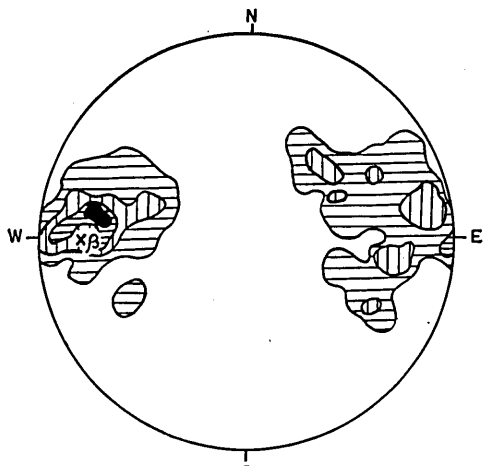

Fig. 3b. Lineation diagram of whole area. Measurements: 52. Contours: 15.1-11.5-5.6-1.8%

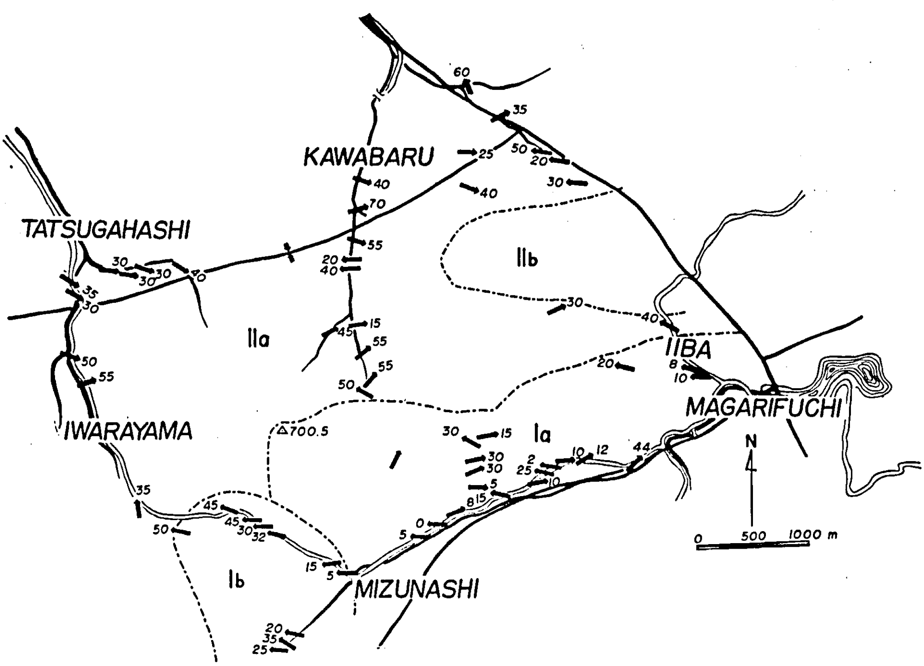

FIG. 4. Structural subdivision and lineation

TABLE 2 STRUCTURAL DIVISION ACCORDING TO THE DEGREE OF DISTINCTION OF LINEATION

SUBAREA I Lineation is distinct in general	Ia occupies the southernpart of the district. Lineation is distinct throughout the area.
	Ib occupies the southwestern part of the district. Lineation is distinct in general, but in some places it is rather indistinct.
SUBAREA II Lineation is indistinct in general	IIa occupies the northern part of the district. Lineation is indistinct in general, but in some places it is rather distinct.
	IIb occupies the eastern part of the central area of the district. Lineation is indistinct.

accordance with β-axis in π-diagram, as shown in fig. 3. Therefore, it is evident that the lineation is parallel to the regional fold axis (B), i.e., it is $B(=b)$-lineation.

Owing to the constant orientation of lineation, this district can not be divided into any subareas according to the variation in trend of the lineation. But, as the degree of development of the lineation is not uniform throughout the district, the metamorphic complex is divided into two subareas and further each subarea is subdivided into two minor areas as shown in table 2 and fig. 4.

C PETROGRAPHY

Main types of the metamorphic rocks are as follows:

Metamorphic rocks derived from argillaceous sediments: Main constituents are quartz, biotite, plagioclase (andesine), accompanied by subordinate sphene, apatite, zircon. Often, garnet and/or tourmaline are found along the boundary of the older granite.

Owing to the alteration, chlorite converted from biotite is sometimes found.

Metamorphic rocks derived from siliceous sediments: Main constituents are quartz, accompanied by subordinate plagioclase, biotite, and common hornblende, which seem to have been derived from narrow feldspathic or basic pyroclastic seams between quartzose ones. Garnet and/or tourmaline are found only in the vicinity of the older granite. Cummingtonite was found only in a specimen collected near Mizunashi.

Metamorphic rocks derived from basic pyroclastic rocks: These are characterized by common hornblende, plagioclase with or without quartz. Sphene, apatite, and magnetite appear as the accessory mineral. Sometimes, garnet and/or epidote are found in the vicinity of the older granite. In rocks with alternating layers of basic pyroclastic and argillaceous matters, biotite, chlorite, and zircon are found. The

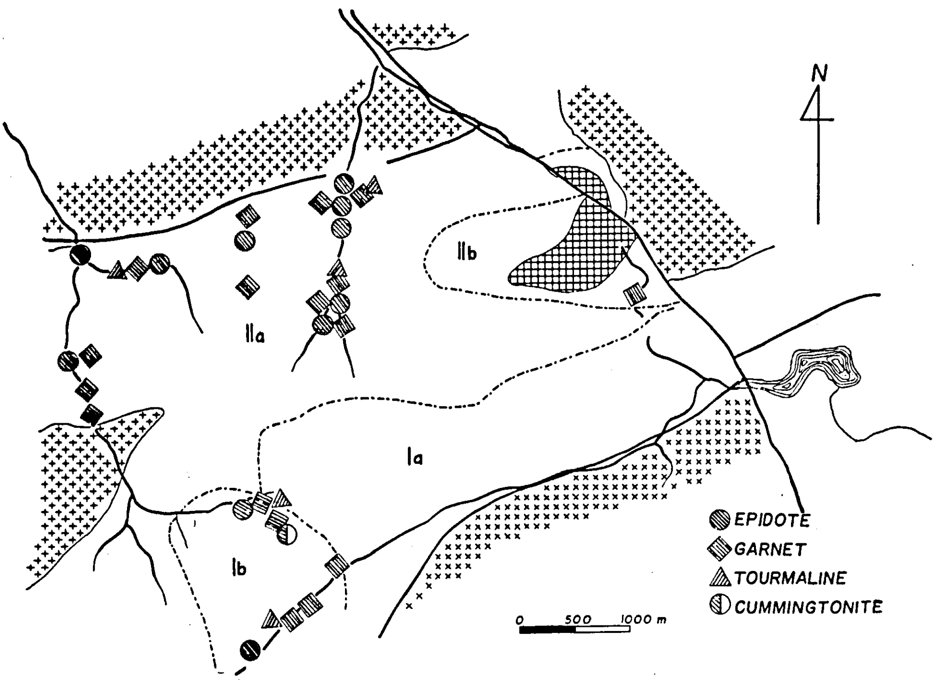

FIG. 5. Distribution of garnet, epidote, tourmaline, and cummingtonite.

occurrence of garnet, epidote, tourmaline, and cummingtonite may be read in fig. 5 and table 3.

On the basis of the distribution of garnet, epidote, tourmaline, and cummingtonite, the writer interpretes those minerals as having been formed under the thermal effect related to the older granite. The formation of a part of biotite and amphibole may be related to the older granite. The problem as to how much parts of biotite and amphibole were formed under the thermal effect of the older granite will be discussed in the later pages.

The genesis of each mineral will be noted briefly in the following:

Garnet: The occurrence of garnet is limited only in the vicinity of the older granite, that suggesting the close relationship of garnet to the older granitic intrusion. The mineral shows neither eyed texture nor vortex structure as is the case in normal crystalline schists. A. HARKER (1932, p. 323) said, "it is to be expected, therefore, that garnet will usually be destroyed in thermal metamorphism. ⋯." If the mineral was formed at the time of regional metamorphism, it should have been destroyed by the thermal effect of the older granite. The existence of garnet in the vicinity of the older granite suggests, therefore, that the mineral is not the survival of regional-metamorphic products, but that it is a newly crystallized product of thermal metamorphism by the older granite. The garnet may have been formed in somewhat calcareous parts of green-schists and quartz-schists under the addition of

TABLE 3 MINERAL

Structural Division		Specimen No.	Original Rock	Mineral: plagioclase	Mineral: quartz	Mineral: biotite	Mineral: amphibolite
Ia	Ikura-Magarifuchi-Mizunashi	3301	B	+	+	+	+
		3302	A	+	+	+	
		42001	B	+			+
		61001	A	+	+	+	+
		61002	B	+			+
		61005	B	+	+		+
Ib	Mizunashi	42006	A	+	+	+	
		42003	A	+	+	+	
		42004	S	+	+	+	+
		42005	B	+	+	+	+
		42007	S	+	+		
		42009	A	+	+		+
		42008	B	+			+
		1307	S	+	+		+
		42011	A	+	+	+	+
IIa	Tatsuhashi-Iwarayama	112301	B	+	+	+	+
		112302	B	+			+
		602401	S	+	+	+	
		1304	A	+	+	+	
		1305	A	+	+	+	
		8805	S	+	+	+	+
		8806	B	+	+	+	+
	Iwara	8807	S	+	+		
		8809	A	+	+	+	
		2102	S	+	+	+	+
		2103	A	+	+	+	
		2107	B	+			+
	Kawabaru	602901	B	+	+		+
		602902	S	+	+	+	
		602903	B	+	+		+
		1706	B	+		+	+
		602904	A	+	+	+	
		602906	S	+	+	+	+
		1708	B	+			+
		602907	S	+	+		+
		1709	B	+	+		+
		1710	B	+	+		+
IIb	Ikuratôge	112607	A	+	+	+	
		61008	B	+			+
		9401	B	+			+
		1704	B	+	+	+	+
		61003	B	+	+		+

A: Argillaceous sediments
S: Siliceous sediments
B: Basic pyroclastic rocks
Plagioclase composition is determined by optic axial angle from figure made by J. R. Smith.

ASSEMBLAGE

Assemblage					Composition of Plagioclase
garnet	epidote	diopside	tourmaline	chlorite	
					$Ab_{61}An_{39}$
					$Ab_{67}An_{33}$ - $Ab_{64}An_{36}$
		+			
					$Ab_{68}An_{32}$ - $Ab_{61}An_{39}$
		+		+	$Ab_{62}An_{38}$ - $Ab_{58}An_{42}$
					$Ab_{62}An_{38}$ - $Ab_{58}An_{42}$
+					$Ab_{66}An_{34}$ - $Ab_{61}An_{39}$
+					$Ab_{68}An_{32}$ - $Ab_{67}An_{33}$
+			+		measurement impossible
	+			+	$Ab_{54}An_{46}$ - $Ab_{58}An_{42}$
				(cummingtonite)	
+				+	measurement impossible
	+			+	$Ab_{54}An_{36}$ - $Ab_{58}An_{42}$
+			+		measurement impossible
					$Ab_{54}An_{46}$ - $Ab_{61}An_{39}$
	+				$Ab_{65}An_{35}$ - $Ab_{58}An_{42}$
					$Ab_{58}An_{42}$ - $Ab_{56}An_{44}$
+	+				$An_{52}An_{48}$ - $Ab_{58}An_{42}$
+				+	$Ab_{66}An_{34}$ - $Ab_{64}An_{36}$
+					$Ab_{68}An_{32}$ - $Ab_{66}An_{34}$
+			+		$Ab_{65}An_{35}$ - $Ab_{58}An_{42}$
	+			+	$Ab_{66}An_{34}$ - $Ab_{58}An_{42}$
				+	
				+	$Ab_{66}An_{34}$ - $Ab_{64}An_{36}$
+					$Ab_{62}An_{38}$ - $Ab_{58}An_{42}$
	+			+	$Ab_{65}An_{35}$ - $Ab_{64}An_{36}$
+					$Ab_{58}An_{42}$ - $Ab_{54}An_{46}$
	+				$Ab_{61}An_{39}$ - $Ab_{58}An_{42}$
+			+		$Ab_{65}An_{35}$ - $Ab_{64}An_{36}$
+	+				$Ab_{61}An_{39}$ - $Ab_{57}An_{43}$
	+				
			+	+	$Ab_{67}An_{33}$ - $Ab_{64}An_{36}$
+	+				$Ab_{68}An_{32}$ - $Ab_{61}An_{39}$
					$Ab_{62}An_{38}$ - $Ab_{54}An_{46}$
	+			+	$Ab_{62}An_{38}$ - $Ab_{58}An_{42}$
					$Ab_{57}An_{43}$ - $Ab_{54}An_{46}$
					$Ab_{57}An_{43}$ - $Ab_{54}An_{46}$
+					$Ab_{62}An_{38}$ - $Ab_{64}An_{36}$
					$Ab_{66}An_{49}$ - $Ab_{47}An_{53}$
					$Ab_{50}An_{50}$ - $Ab_{51}An_{49}$
				+	$Ab_{66}An_{34}$ - $Ab_{58}An_{42}$
					$Ab_{50}An_{50}$ - $Ab_{57}An_{43}$

heat from the older granite, and therefore, it may well be that the newly crystallized garnet is not almandine but grossularite.

Epidote: The mineral appears also only in the vicinity of the older granite as garnet, forming sometimes epidote band. Epidote is also interpreted as formed by the thermal effect of the older granite in somewhat calcareous parts.

Tourmaline: The mineral can appear in normal crystalline schists, but in this district, its appearance is limited only in the vicinity of the older granite, that suggesting the thermal origin of tourmaline, probably, under the addition of volatile matters from the older granite.

Cummingtonite: It is found only in a specimen of siliceous rock collected in the Subarea Ib. It appears as bands. The cummingtonite may have been formed by the addition of MgO or subtraction of CaO under the thermal effect of the older granite.

D Petrofabrics

In order to solve the problem as to how much parts of biotite and amphibole were formed by the thermal effect of the older granite, the writer conduced petrofabric analysis on the preferred orientation of constituent minerals, i. e., quartz, amphibole, and biotite. Their data are collected and tabulated in tables 4 and 5, and the fabric diagrams are shown on the map in plates 2,3, and 4.

1 Quartz fabrics

As quartz is the most sensitive mineral to the thermal effect, the thermal metamorphism related to the older granite should be most sensitively reflected in the feature of fabric pattern of quartz. The writer, therefore, attempted petrofabric analysis of quartz on specimens collected through his field survey.

300 *c*-axes of the mineral were measured and plotted for each specimen, and the features of fabric patterns are summarized in table 4. and the fabric diagrams are shown on the map in plate 2. From table 4 and plate 2 close relationship between the structural division mentioned in Chapter C and the features of fabric patterns can be read, namely, types *f* and *g* after the classification of quartz pattern by H. W. Fairbairn (1949) are predominating in Subarea I. On the other hand, asymmetric patterns are predominating in Subarea II.

From above facts, it may safely be said that the thermal effect of the older granite is weaker in Subarea I than in II. Types *f* and *g* of quartz pattern are found, however, even in Subarea II, as represented by such specimens No. 602401, 602905, and 602902. In such cases, as the lineation whithin the bedding-schistosity plane is rather distinct, it is suggested that these specimens underwent the thermal effect to a lesser degree than the other in Subarea II.

From above descriptions it is reasonably concluded that a greater part of quartz in Subarea II underwent thermal effect, and that the degree of the effect, however, decreases in proportion to the distance from the older granite. The fabric pattern of quartz imprinted at the time of regional metamorphism remains in Subarea I, especially in Subarea Ia.

TABLE 4 QUARTZ FABRIC PATTERN

DIVISION	SPECI-MEN No.	POSITIONS OF PRINCIPAL MAXIMA	POSITIONS OF SUBORDINATE MAXIMA	FABRIC PATTERN	DISTINCTION OF LINEATION
Ia	3302	III (3)	III (1, 2)	*g* pattern	distinct
	61001	III (1, 2, 3, 4)		*g* 〃	〃
	61002	III (2, 3)	III (1, 4)	*g* 〃	〃
	42006	III (2, 4)	III (3)	*g* 〃	〃
Ib	42003	III (1,3) IV (2)	III (4)	*g* 〃	〃
	42004	IV (4)	IV (2)	modification of *f* pattern	rather distinct
	42005	III (1, 3, 4)	III (2)	*f* pattern	distinct
	42007	IV (1)	IV (2)	*f* 〃	〃
	42009	III (1) IV (2)	III (3)	modification of *g* pattern	rather distinct
	1307	II, III (3)	III (1)	*f* pattern	distinct
IIa	602401	III (1, 3)	III (2)	*g* 〃	rather distinct
	1304	III (1, 3)		asymmetry	indistinct
	1305	III (1)		〃	〃
	8805			〃	〃
	8807			〃	〃
	8809			〃	〃
	2102	III (1)		〃	〃
	2103			〃	〃
	2904	III (2)		〃	〃
	2905	III (2, 3)	III (1)	*g* pattern	rather distinct
	2902	III (4)		modification of *f* pattern	〃
	2907	III (2, 3)		modification of *g* pattern	〃
IIb	112607	II		asymmetry	indistinct

1. Roman numerals show the point of axis concentration designated by SANDER.
2. Parenthesized number is quadrantal number.

2 *Amphibole fabrics*

The amphibole was determined to be common hornblende by the following optical properties:- $c \wedge Z = 15^\circ \sim 16^\circ$, 2V about $X = 60^\circ \sim 65^\circ$, opt. plane //(010), pleochroism: X light-yellow, Y yellowish-green, Z bluish green.

Though optic elasticity axes were measured for 150 or 120 grains of amphibole, petrofabric diagrams in the map (plate 3) are shown only for Y axis. The summary of features of these petrofabric diagrams is tabulated in table 5. In respective diagrams the dispersion of principal maxima, and girdle pattern about *b* and *c* can be recognized. Recently, G. KOJIMA and K. HIDE (1958) reported in a region of the regional type of metamorphism of the Sambagawa metamorphic zone that the position of principal maxima for Y in amphibole petrofabric diagram is situated in *a* or *b*, suggesting that the former corresponds to the direction of sliding and the latter to the axis of folding. In this district, the position of principal maxima is generally oriented towards *a*. The features of petrofabric patterns in each Subarea

Table 5 Amphibole Fabric Pattern

Structural Division	Specimen No.	Fabric Pattern			Distinction of Lineation
		max. point	girdle about *b*	partial girdle about *c*	
Ia	3301	*a* & *b*	indistinct	indistinct	rather distinct
	42001	*a*	indistinct	rathe distinct	distinct
	61002	*a*	indistinct	rather distinct	distinct
	61005	*a*	indistinct	rather distinct	distinct
Ib	42005	*a*	distinct partial girdle	distinct	rather distinct
	42008	*a*	distinct partial girdle	distinct	rather distinct
IIa	112302	in-definite	complete girdle	distinct	indistinct
	8806	*a*	complete girdle	distinct	indistinct
	2107	*a*	complete girdle	indistinct	rather distinct
	2903	*a*	indistinct	rather distinct	indistinct
	1706	*a*	distinct partial girdle	indistinct	rather distinct
	1708	*a*	complete girdle	distinct	indistinct
	1709	*a*	distinct partial girdle	distinct	rather distinct
	1710	*a*	distinct partial girdle	rather distinct	rather distinct
	1704	in-definite	complete girdle	distinct	indistinct
IIb	61008	*a*	distinct partial girdle	distinct	rather distinct
	9401	in-definite	complete girdle	distinct	indistinct
	61003	in-definite	indistinct	distinct	indistinct

will be described in the following:-

Amphibole fabrics in Subarea Ia The position of principal maximum is situated in *a* and the position of submaxima in *b* in each specimen. Girdle about *b* or *c* is in distinct. Therefore, the petrofabric diagrams bear a very close analogy with that of the Sambagawa crystalline schists.

Amphibole fabrics in Subarea Ib Principal maxima are dispersed, girdle about *b* is partial, and partial girdle about *c* is distinct.

Amphibole fabrics in Subarea II With regard to the feature of amphibole petrofabric pattern, no particular difference between Subareas IIa and IIb can be recognized, and so the writer will discuss IIa and IIb together.

Except for specimens No. 2903 and 1707, which are analogous to the feature of fabric pattern of Subarea Ia, principal maxima are generally dispersed or oriented towards *a*, girdle about *b* becomes complete, and partial girdle about *c* is distinct.

From the fact above noted, it can be said that in proportion to the distance from the older granite, the degree of dispersion of maxima decreases, girdle about *b* retrogrades to partial girdle from complete girdle, and partial girdle about *c* becomes indistinct. These facts may be interpreted in terms of thermal effect related to the intrusion of the older granite, namely, the dispersion of principal maxima, the formation of girdle about *b* and the distinction of partial girdle about *c* are due to thermal recrystallization, and, therefore, the features of petrofabric patterns in Subarea Ia must be original, formed at the time of regional metamorphism.

3 Diopside fabrics

The appearance of diopside is limited to Subarea Ia. Optical elastisity axes are measured for 150 grains diopside in a thin section with amphibole, and the microfabric diagram for Y is shown in fig. 6. The principal maximum is oriented in *a* as in the case for amphibole. It may well be concluded, therefore, that diopside was formed with amphibole at the time of metamorphism of regional type.

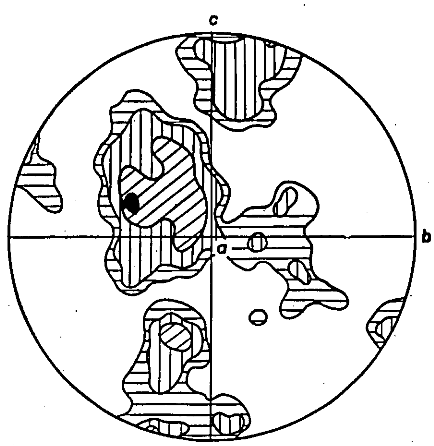

FIG. 6. 150 Y-axes (crystallographic axes *b*) of diopside from plagioclase-amphibolite of Magarifuchi (No. 42001). Contours: 6-4-2-1 %

4 Biotite fabrics

150∼200 poles of cleavage flakes were measured for each specimen, and microfabric patterns are shown in plate 4. The marked dimensional orientation is shown in the diagram as strong maxima in *c*. Some poles are dispersed and partial girdle about *b* appears. In general, partial girdle about *b* and the dispersion of poles predominate in Subareas other than Subarea Ia, but the feature of biotite microfabric pattern is not so different among Subareas as is the case for quartz and amphibole mentioned above. This fact may be interpreted as that the orientation of biotite is strongly controlled by bedding-schistosity plane (*ab*-plane). Accordingly, the intimate relationship between the biotite microfabric and structural subdivision is not so distinct.

E MUTUAL RELATION BETWEEN CONSTITUENT MINERALS AS VIEWED FROM PETROFABRIC STANDPOINT

1 Mutual relation between quartz and amphibole.

In Subarea Ia, the petrofabric diagrams of quartz show type *g*, while amphibole fabric patterns are analogous to the feature of those in the Sambagawa crystalline schists. The same relation as above said can be established on single thin section, as specimen No. 61002.

In subarea Ib, the fabric diagrams of quartz are characterized by types *g* and *f*, and those of amphibole show partial girdle about *a* and *c*. In single thin section, such as specimen No. 42005, the same relation is recognized.

In Subarea IIa, except specimens No. 602401 and 602902, asymmetrical quartz fabric patterns occur combined with amphibole fabric patterns which are characterized by complete girdle about *b* and distinct partial girdle about *c*. In single

TABLE 6 MUTUAL RELATION BETWEEN MAIN THREE CONSTITUENT MINERALS (QUARTZ, AMPHIBOLE, BIOTITE)

Division	Original Rocks	Quartz Fabric Pattern	Amphibole Fabric Pattern			Biotite Fabric Pattern		
			Position of Principal Maxima	Girdle about *b*	Girdle about *c*	Position of principal maxima	Ggirdle about *b* (rotation angle)	Degree of dispersion
Ia	A	*g*-pattern	—	—	—	*c*	80°	not conspicuous
	S	*g*-pattern	*a*	obscure	rather conspicuous	—	—	—
	B	—	*a* (or *b*)	obscure	rather conspicuous	*c*	80°	not conspicuous
Ib	A	*g*-pattern or modification of *g*-pattern	—	—	—	*c*	80°∼100°	conspicuous
	S	*f*-pattern or modification of *f*-pattern	*a*	partial girdle	conspicuous	—	—	—
	B	*f*-pattern	*a*	partial girdle	conspicuous	—	—	—
IIa	A	asymmetrical pattern	—	—	—	*c*	100°∼120°	conspicuous
	S	asymmetrical pattern or modificatior of *f* or *g*-pattern	—	—	—	—	—	—
	B	—	*a*	complete girle or conspicuous partial girdle	conspicuous	—	—	—
IIb	A	asymmetrical pattern	—	—	—	*c*	100°	conspicuous
	S	—	—	—	—	—	—	—
	B	—	indefinite (in some places, *a* or *b*)	complete girdle	conspicuous	—	—	—

A: Argillaceous sediments
S: Siliceous sediments
B: Basic pyroclastic rocks

thin section, however, above relation can not be determined, because plagioclase-amphibolite does not contain enough quantity of quartz to enable any petrofabric analysis, while biotite-quartz-schists do not contain amphibole at all.

In Subarea IIb, asymmetrical quartz fabric patterns occur combined with the amphibole fabric patterns characterized by complete girdle about *b* and distinct partial girdle about *c*. In single thin section, however, above relation can not be determined for the same reasons as for Subarea IIa.

Judging from above statements, there is a general tendency that the degree of symmetry in quartz fabric patterns is reversely proportional to the degree of completeness of girdle about *b* and distinction of girdle about *c* in amphibole fabric patterns.

2 *Mutual relation between quartz and biotite*

Because quartz is a highly sensitive mineral to thermal as well as dynamic recrystallization, quartz fabric patterns in this district have their own characteristic features in each Subarea, while that is not the case for biotite, because the orientation of biotite is strongly controlled by *ab*-plane. In Subarea Ia the feature of quartz fabric patterns are represented by type *g*, and no biotite fabrics show so remarkable dispersion as in the other Subareas. In other Subareas than Ia, no particular microfabric relation between both minerals can not be recognized.

3 *Mutual relation between amphibole and biotite*

The paragenesis of biotite and amphibole is rarely found. The feature of biotite fabric pattern is not so much variable throughout the district. Accordingly, the relation between the microfabric features of both minerals is not so distinct.

F Summary

Above descriptions on petrography and structure, especially petrofabric may be summarized as follows.

i) *Subarea Ia*: Lineation is distinct. The thermal effect of the older granite can not be traced in this Subarea, metamorphic minerals such as epidote, garnet, tourmaline, and cummingtonite are not found, while diopside formed during the metamorphism of regional type does appear. The fabric patterns of quartz and amphibole preserve the original features related to the regional metamorphism.

ii) *Subarea Ib*: Lineation is generally distinct, but in some places rather indistinct. Though the recrystallized minerals such as garnet, tourmaline, and cummingtonite appear, the petrofabric pattern of quartz remains its original character, and amphibole fabric pattern is more or less changed from the original pattern.

iii) *Subarea IIa*: Lineation is rather indistinct, but in some places distinct. Minerals recrystallized by the thermal effect such as garnet, epidote, and tourmaline appear, and the features of fabric patterns of quartz and amphibole, which were formed during the regional metamorphism, are changed because of the thermal recrystallization. In some places, however, their original feature is preserved.

iv) *Subarea* IIb: Lineation is indistinct. Thermally recrystallized garnet appears. The original feature of microfabric pattern can not be detected.

From the fact above summarized, the Subareas may be arranged in the order of intensity of thermal effect by the older granite as follows. Subarea IIb······?···→Subarea IIa→Subarea Ib→Subarea Ia.

G Concluding Remarks

On the basis of the following facts and interpretations, it may well be concluded that the metamortphic rocks in the Seburi district attained to the amphibolite facies at the time of the regional metamorphism.

i) Based on the mode of occurrence of garnet, epidote, tourmaline, and cummingtonite, these minerals can be regarded as formed newly by the thermal effect, probably accompanied by the addition of materials from the older granite.

ii) Judging from the results of fabric analyses, a part of amphibole and quartz may have been recrystallized at the time of intrusion of the older granite, but the greater part of them must have been formed at the time of the regional metamorphism.

iii) As shown by the conformable relation between the microfabric patterns of amphibole and diopside, the assemblage diopside-plagioclase-amphibole is the product of higher-grade metamorphism of regional type.

iv) Judging from the intimate association of plagioclase-amphibolite and biotite-quartz-schists as shown in the geological map (plate 1), the diopside-plagioclase-amphibolite and plagioclase-amphibolite must have been derived from supracrustal rocks, not from synkinematic intrusives.

v) The rock streuture of diopside-plagioclase-amphibolite and a part of plagioclase-amphibolite in Subarea Ia are gneissic, and plagioclase is commonly medium andesine in composition, as shown in table 3, that suggesting the presence of higher-grade metamorphism in this district prior to the older granitic intrusion.

vi) Metamorphic rocks derived from argillaceous sediments are represented by such assemblages as biotite-quartz-plagioclase and garnet-biotite-quartz-plagioclase. The fact, that biotite microfabric patterns are generally characterized by the dispersion of poles of cleavage flakes, suggests the recrystallization at the time of the older granitic intrusion.

From the above statements it can be concluded that the metamorphic rocks in this district, derived from supracrustal rocks, had attained to the amphibolite facies, as represented by such assemblages as hornblende-plagioclase and diopside-hornblende-plagioclase during the dynamo-thermal metamorphism before the intrusion of the older granite.

IV Significance of the Present Study in the Basement Geology of Northern Kyûshû

The basement metamorphic rocks of Northern Kyûshû have been generally believed among geologists to be composed of rocks of the muscovite-chlorite subfacies of low-grade regional matamorphism, and the higher-grade metamorphic rocks belonging to the Sangun metamorphic zone have been attributed to the thermal effect of older or younger granites enclosing them. Recently, however, geological and petrological studies made by petrologists revealed the presence of rocks of the biotite-chlorite subfacies of regional metamorphism in the Chikugo and the Asakura (?) district. Furthermore, metamorphic rocks of higher-grade referred to epidote-amphibolite facies have been described by H. MAIKUMA in the Sasaguri district.

In the Seburi district, there are metamorphic rocks much higher in grade than them. The present writer has proved the existence of crystalline schists of the amphibolite facies by means of petrofabric analysis.

After H. MAIKUMA, a higher-grade dynamo-thermal metamorphism of the epidote-amphibolite facies was overprinted on pre-existing low-grade phyllites in the Sangun Mountainland, where the general trend of the phyllite is N-S, while that of the higher-grade schists is E-W. Overprinting of metamorphism such as revealed in the Sangun Mountainland can not be detected in the present study, that being probably due to the intensive nature of high-grade dynamo-thermal as well as thermal metamorphism in the Seburi Mountainland. Judging from the situation of these mountainlands in the basement geology of Northern Kyûshû, i.e., the facts that i) the trend of higher-grade metamorphic formation in the Seburi Mountainland represents the western extension of that of the Sangun Mountainland, and that ii) the rock association is quite common between these two montainlands, characterized by the predominance of green-rocks, it can safely be said that the high-grade schists of both mountainlands represent the existence of a zone of high-grade metamorphism of dynamo-thermal type in Northern Kyûshû, having a general trend of E-W, which crosses the structure of pre-existing lower-grade phyllites of regional metamorphic type.

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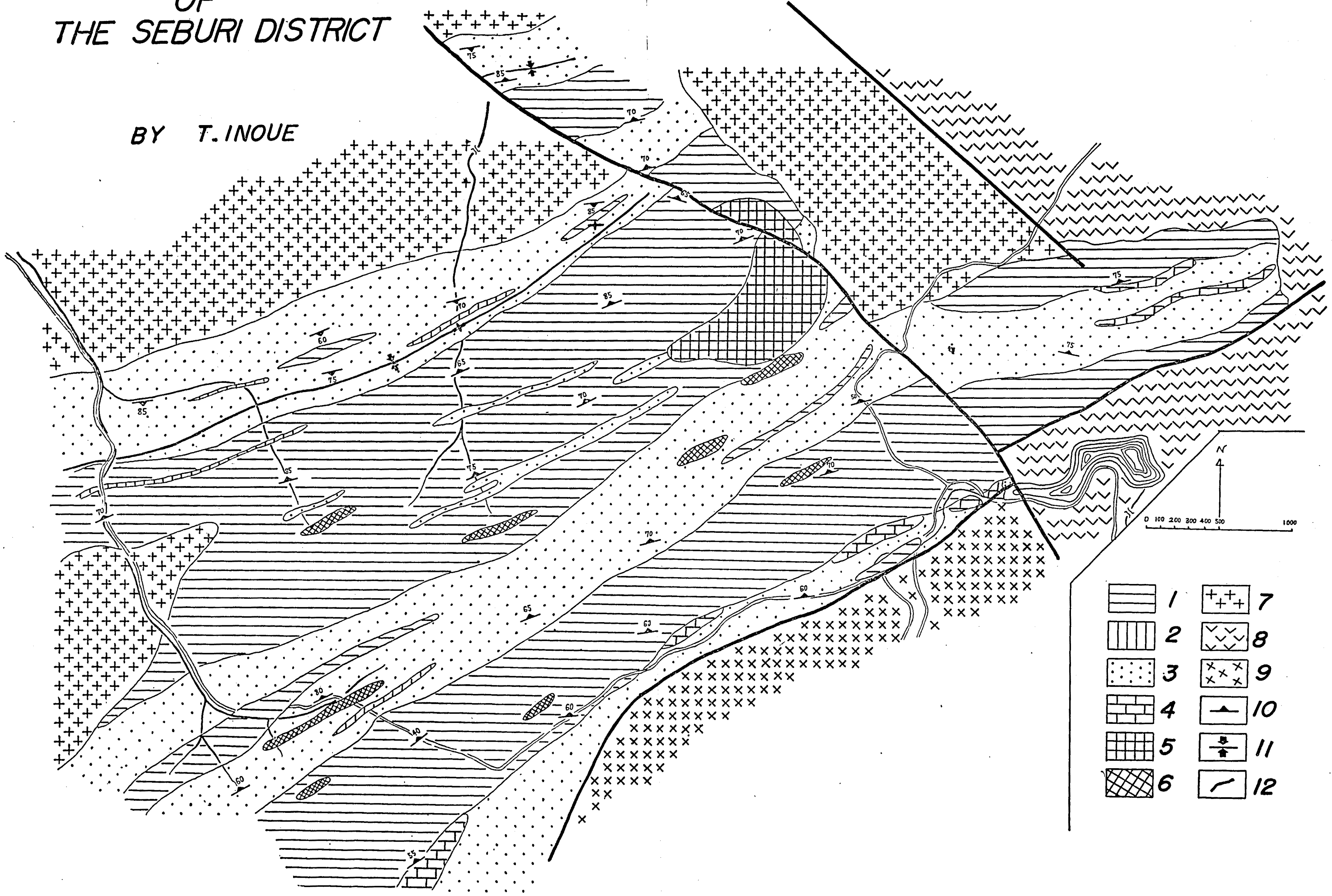
Explanation of Plate XLIV

Geological map of the Seburi district

1 Metamorphic rocks derived from argillaceous sediments
2 Metamorphic rocks derived from siliceous sediments
3 Metamorphic rocks derived from basic pyroclastic and volcanic rocks
4 Crystalline limestone
5 Metagabbro
6 Ultrabasic rocks
7 Granodiorite (the Itoshima type)
8 Muscovite-biotite-granite (the Sawara type)
9 Biotite-granite (the Kaho type)
10 Dip and strike of bedding-schistosity plane
11 Syncline
12 Fault

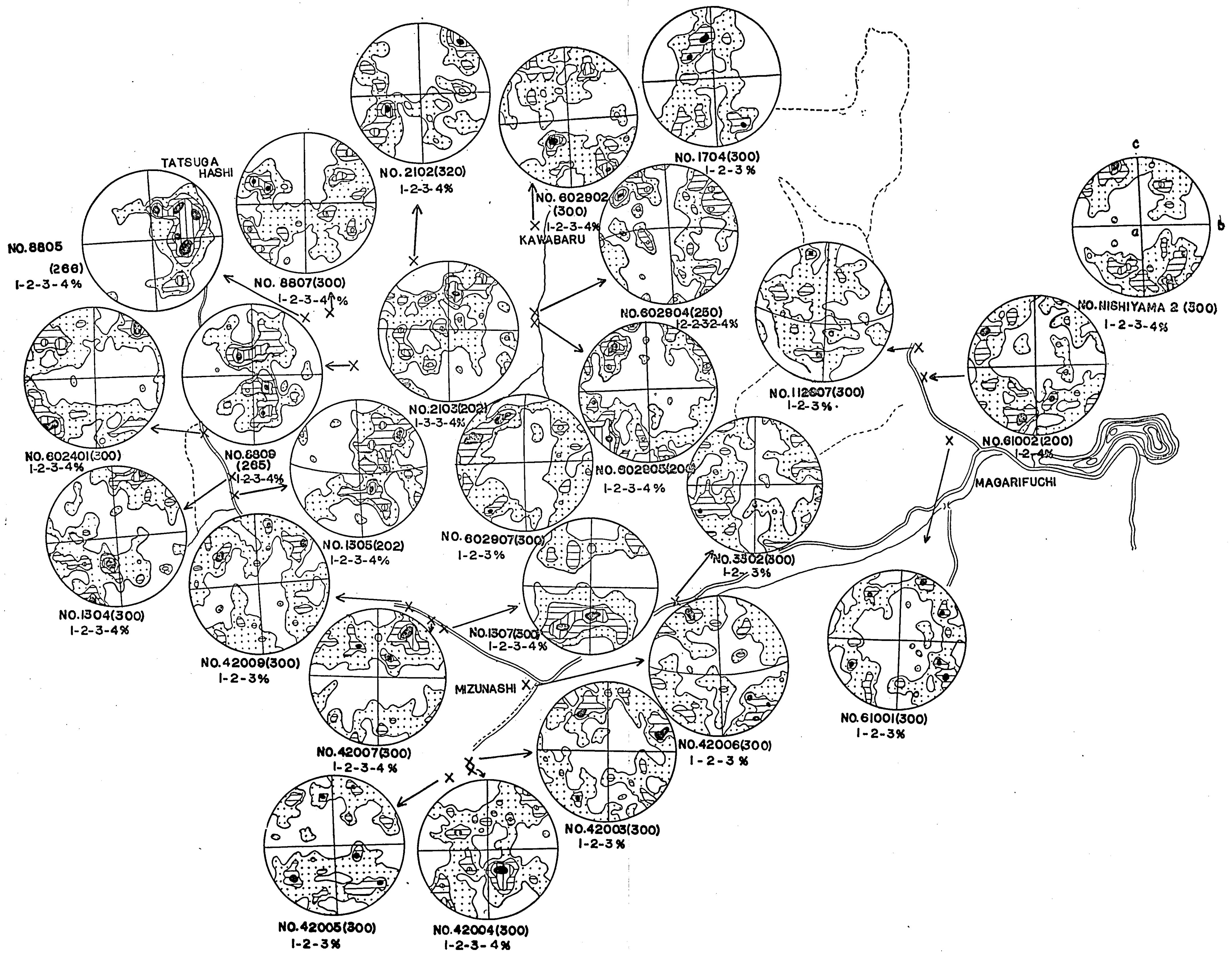
GEOLOGICAL MAP OF THE SEBURI DISTRICT

BY T. INOUE



Explanation of Plate XLV

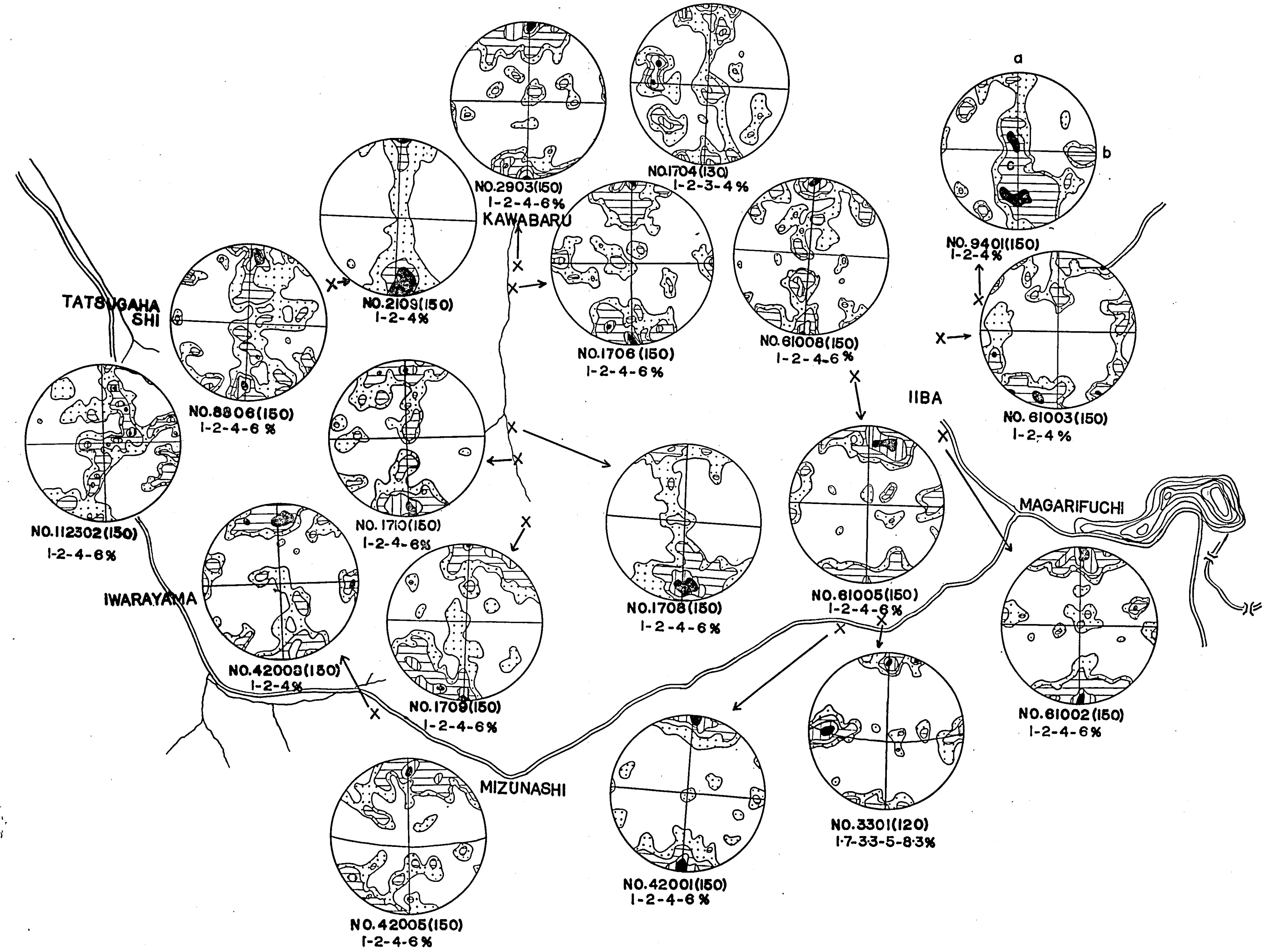
Distribution of microfabric diagrams of quartz in the Seburi district. All *bc*-section, as represented by a diagram of NE corner. The number in the parenthesis is that of measurement.



TATSUGA HASHI
NO. 8805 (266) 1-2-3-4%
NO. 8807(300) 1-2-3-4%
NO. 2102(320) 1-2-3-4%
NO. 602902 (300) 1-2-3-4%
KAWABARU
NO. 1704(300) 1-2-3%
NO. 602904(250) 1-2-3-4%
NO. 2103(202) 1-3-3-4%
NO. 602401(300) 1-2-3-4%
NO. 8809 (265) 1-2-3-4%
NO. 1305(202) 1-2-3-4%
NO. 602907(300) 1-2-3%
NO. 602905(200) 1-2-3-4%
NO. 112807(300) 1-2-3%
NO. NISHIYAMA 2 (300) 1-2-3-4%
NO. 61002(200) 1-2-4%
MAGARIFUCHI
NO. 3502(300) 1-2-3%
NO. 1304(300) 1-2-3-4%
NO. 42009(300) 1-2-3%
NO. 1307(300) 1-2-3-4%
MIZUNASHI
NO. 42007(300) 1-2-3-4%
NO. 42006(300) 1-2-3%
NO. 61001(300) 1-2-3%
NO. 42003(300) 1-2-3%
NO. 42005(300) 1-2-3%
NO. 42004(300) 1-2-3-4%

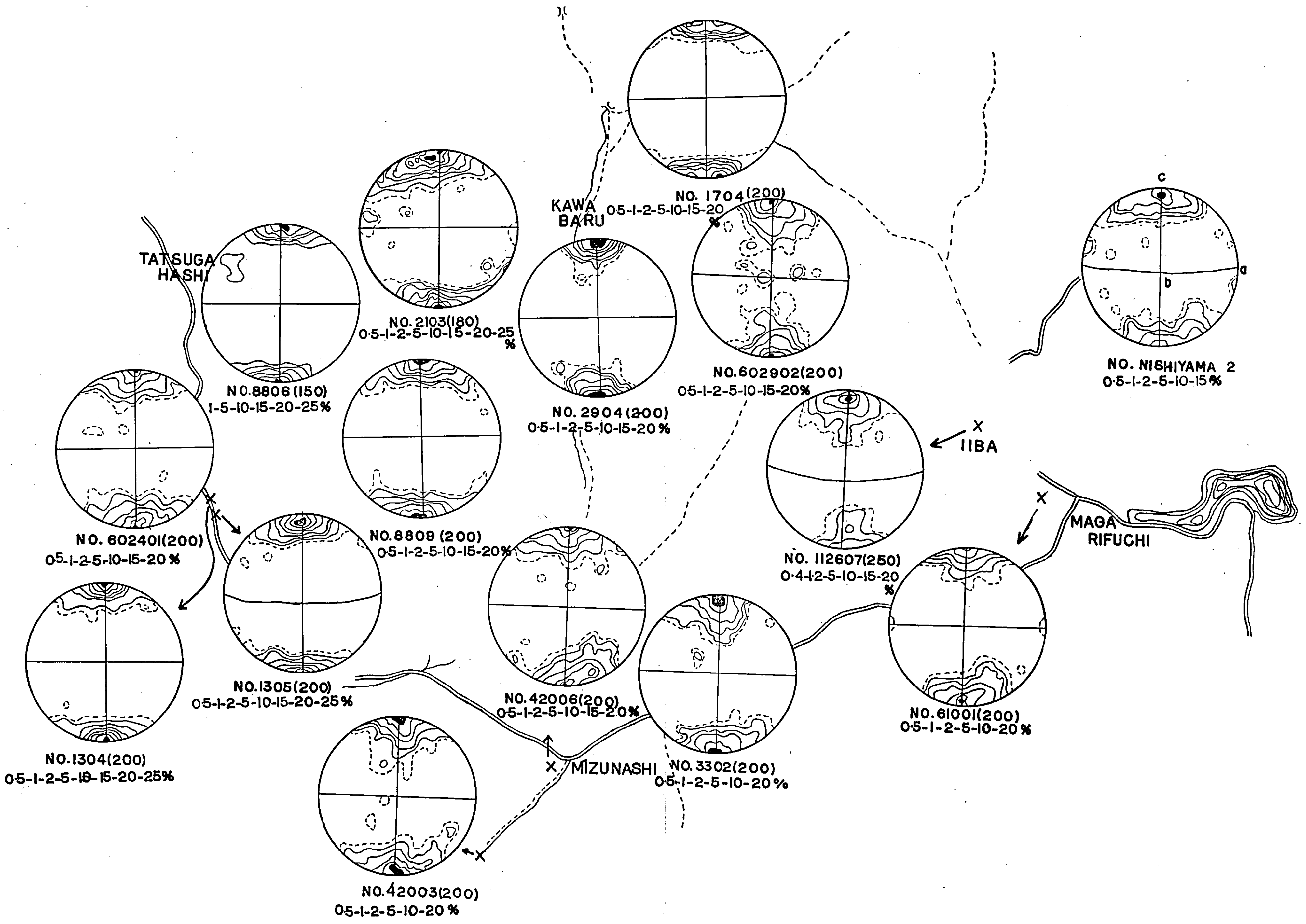
Explanation of Plate XLVI

Distribution of microfabric diagrams of amphibole in the Seburi district. All *ab*-section, as represented by a diagram of NE corner.


TATSUGAHASHI
IWARAYAMA
KAWABARU
IIBA
MAGARIFUCHI
MIZUNASHI
NO.112302(150) 1-2-4-6%
NO.8806(150) 1-2-4-6%
NO.2109(150) 1-2-4%
NO.2903(150) 1-2-4-6%
NO.1704(130) 1-2-3-4%
NO.9401(150) 1-2-4%
a
b
NO.1706(150) 1-2-4-6%
NO.61008(150) 1-2-4-6%
NO.61003(150) 1-2-4%
NO.1710(150) 1-2-4-6%
NO.42003(150) 1-2-4%
NO.1709(150) 1-2-4-6%
NO.1708(150) 1-2-4-6%
NO.61005(150) 1-2-4-6%
NO.61002(150) 1-2-4-6%
NO.42005(150) 1-2-4-6%
NO.42001(150) 1-2-4-6%
NO.3301(120) 1·7-3·3-5-8·3%

EXPLANATION OF PLATE XLVII

Distribution of microfabric diagrams of biotite in the Seburi district. All *ac*-section, as represented by a diagram of NE corner.



NO. 1704(200)
05-1-2-5-10-15-20 %
KAWA BARU
TATSUGA HASHI
NO. 2103(180)
0·5-1-2-5-10-15-20-25 %
NO.8806 (150)
1-5-10-15-20-25%
NO. 2904 (200)
0·5-1-2-5-10-15-20%
NO.602902(200)
05-1-2-5-10-15-20%
c
a
b
NO. NISHIYAMA 2
0·5-1-2-5-10-15%
IIBA
NO. 602401(200)
05-1-2-5-10-15-20%
NO.8809 (200)
05-1-2-5-10-15-20%
MAGA RIFUCHI
NO. 112607(250)
0·4-1-2-5-10-15-20 %
NO.1305(200)
0·5-1-2-5-10-15-20-25%
NO.1304(200)
05-1-2-5-10-15-20-25%
NO.42006(200)
05-1-2-5-10-15-20%
NO. 3302(200)
05-1-2-5-10-20%
NO.61001(200)
05-1-2-5-10-20%
MIZUNASHI
NO.42003(200)
05-1-2-5-10-20 %