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Chemical Composition of Basic Schists from the Sangun Metamorphic Terrain in the Nishiki-chô District, Yamaguchi Pref., Japan

By

Yûjirô NISHIMURA

with 4 Tables and 15 Text-figures

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ABSTRACT: In the Sangun metamorphic terrain of the Nishiki-chô district, characterized by glaucophanitic metamorphism, basic schists such as greenschists and glaucophane schists occur abundantly as lenticular or amoeba-shaped bodies within some definite stratigraphic horizons. The origin and the chemistry of the basic schists have been investigated on the field as well as on the petrochemical point of view hitherto applied mainly to igneous rocks. Original rocks of the basic schists are regarded as sills intruded into water-saturated pelites in the geosynclinal phase. The basic sill is divided petrographically and petrochemically into two parts. One is the most peripheral zone of the sill, which is composed of pale-green, schistose, fine-grained rocks and shows fairly abnormal bulk composition between gabbroic and pelitic rocks (type II). The other is the main part of the sill, which consists of coarse-grained green rocks, showing normal gabbroic composition (type I). The bulk chemistry in the main part varies systematically from the marginal layer to the central part wihin a sill. The regularity of features of the intruded basic body is described in detail and genetically considered. Petrochemical characters of the basic schists along with the mineralogy of relic clinopyroxenes demonstrate that the basic schists of the Nishiki-chô district have been derived from rocks of the alkalic rock series.

CONTENTS

I. INTRODUCTION

In recent years, the study of regional metamorphism has been focused on the physical condition of mineralization, specifically temperature and pressure, based on the experiment as well as on the thermochemical calculation. MIYASHIRO (1961) has presented a scheme of classification of the metamorphic facies series, in which three principal facies series and two transitional ones were discriminated. MIYASHIRO (1967, 1968) concluded that the metamorphic belt of high P/T type is accompanied by abundant ophiolitic rocks but is devoid of granitic ones, whereas that of low P/T type is accompanied by a great amount of granitic rocks but is poor in ophiolitic ones.

Granitic rocks in the metamorphic belt have hitherto been studied in detail from many parts of the world from various points of view, while ophiolitic complex, including basic to ultramafic rocks, has called little attention. HASHIMOTO (1964) reviewed this problem and summarized that the original igneous rocks tend to be more alkalic in glaucophanitic terrains than in non-glaucophanitic ones.

The Sangun metamorphic rocks are widely distributed on the eastern part of Yamaguchi Prefecture. KOJIMA and his collaborators have worked mainly on the geologic structure and the stratigraphy in this district (KOJIMA and SASAKI, 1950; KOJIMA, 1953; OKAMURA, 1953, 1963; NISHIMURA and NUREKI, 1966). As a result of these studies, it has been suggested that most of basic metamorphic rocks in this district would have been derived from intrusives chemically of basaltic composition. The facies series of regional metamorphism of the Sangun metamorphites of the Nishiki-chô district, Yamaguchi Prefecture, corresponds to a high-pressure intermediate group (NISHIMURA, 1971).

In this paper, the author intends to show petrochemical characters as well as related chemical processes taken place in the geosynclinal pile of sediments, on the basis of detailed field survey and 68 bulk chemical analyses of basic schists.

The full report on the geology and petrology of this district will be given elsewhere (NISHIMURA, 1971).

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He is also grateful to the staff of the Kawayama Mine, Nihon Mining Co., who gave him opportunities to use the data of drill holes and to examine the drill cores.

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II. GEOLOGICAL SETTING

A. OUTLINE OF GEOLOGY

The zonal structure of the basement geology has been detected on the eastern part of Yamaguchi Prefecture. The basement rocks are divided from north to south into the slightly metamorphosed Paleozoic formation, the Sangun crystalline schist complex and the Ryôke metamorphic rocks. These basement rocks were overlain unconformably by Late Mesozoic rhyolitic pyroclastics and were intruded by batholithic intrusives of mainly Late Mesozoic granitic rocks. The Nishiki-chô district in question has been left unaffected by the granitic rocks (Fig. 1).

The Sangun crystalline schist complex and the slightly metamorphosed Paleozoic

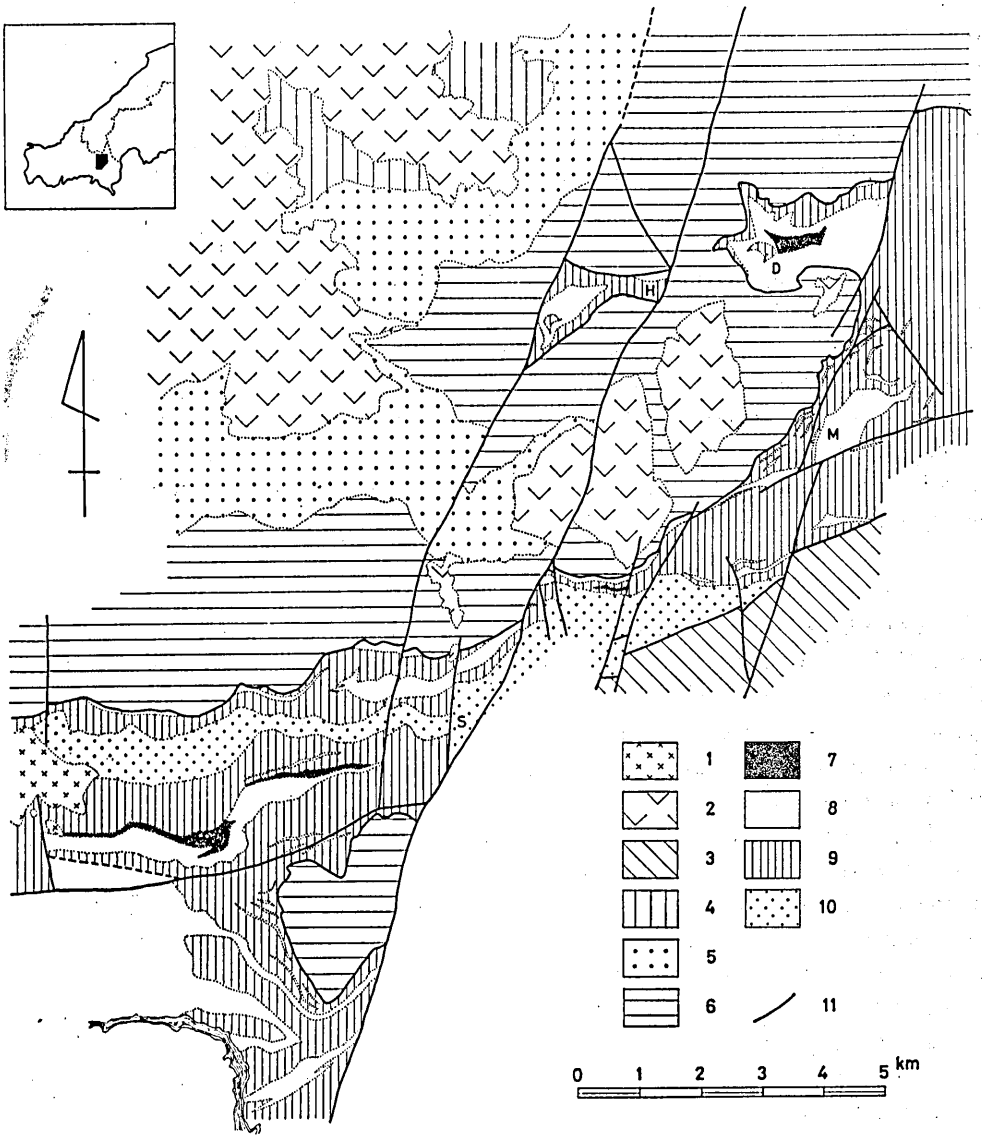

FIG. 1. Geological map of the Nishiki-chô district.
1: Andesite, 2: Rhyolitic pyroclastics, 3: Kuga Group, 4-6: Nishiki Group (4: Upper formation, 5: Middle formation, 6: Lower formation), 7-10: Tsuno Group (7-9: Upper formation, 7: Ultramafic rocks, 8: Basic schists, 9: Pelitic schists, 10: Lower formation), 11: Fault and tectonic slide.
D: Deai, H: Hirose, M: Miyanokushi, S: Suma.

formation are widely developed in this district. The schist complex consists of pelitic, psammitic, basic, siliceous and calcareous schists. Basic schists under consideration are found sporadically in certain horizons throughout the Sangun crystalline schist terrain in the eastern part of Yamaguchi Prefecture including the district in question. They are associated with pelitic, siliceous and calcareous schists. The original formation of these crystalline schists is presumed to correspond mainly to the Carboniferous in age.

The Paleozoic formation, slightly metamorphosed, which is stratigraphically upper than the Sangun crystalline schist complex mainly consists of pelitic, psammitic and acidic pyroclastic rocks, corresponding probably to the Early to Late Permian in age.

The Paleozoic formations, both crystalline schists and slightly metamorphosed rocks, show anticlinal and synclinal structures characterized by gentle wavy form, the axes of which are approximately horizontal, trending east–west. A distinct shear zone, named formerly the "Kitayama overthrust" by Kojima (1947), is observed at the boundary between the underlying Sangun crystalline schist complex and the overlying slightly metamorphosed formation and can be traced extensively in the surrounding region. This structure is believed to have been simultaneous with the tectonic movement related to the formation of major geologic structure, presumably reactivated in later geologic age. This would represent a kind of tectonic slide (Nishimura and Nureki, 1966; Nishimura, 1971).

B. Occurrence and Nature of Basic Schists on the Field

Stratigraphy of the Paleozoic formations, including the Sangun crystalline schists, of the Nishiki-chô district was investigated in some detail by Nishimura and Nureki (1966) and Nishimura (1971). After them, the stratigraphic succession as shown as a general columnar section in Fig. 2 is tentatively presented. The Sangun crystalline schist complex and the slightly metamorphosed Paleozoic formation have been named the Tsuno Group and the Nishiki Group, respectively.

Although basic schists occur throughout the whole area of the metamorphic terrain, they concentrate distinctly in the upper formation of the Tsuno Group and are almost lacking in its lower formation and in the Nishiki Group (see Fig. 2). In the upper formation of the Tsuno Group, attaining about 1,000 m in thickness, two or three horizons of basic schists are detectable.

Basic schists occurring in the uppermost part of the Tsuno Group form generally thin layers, which vary in thickness from several centimeters to a few meters, alternated with pelitic schists concordantly. Most of these rocks are light-greenish in color, with schistose fabric. Basic schists in the lower parts form relatively larger masses of lenticular or amoeboid forms with the thickness of about 250 m. These are green to dark green in color and are less schistose, rather massive. It should be noted that the peripheral parts of these larger lenticular masses of basic schists, in contact with pelitic schists, show light-greenish color, being more schistose than the main part of the basic schist mass. These peripheral zones are closely similar to the thin-layered type of basic schists mentioned above.

Larger basic masses of lenticular or amoeboid forms seem to be concordant macroscopically to the structure of surrounding schists of sedimentary origin. In some outcrops, however, features suggesting disconcordant intrusion of the basic masses into the surrounding schists are observable. No pillow structure is observed. Ultramafic rocks apparently derived from peridotite intrusion accompany the large masses of basic schists in some places (Fig. 1).

These features of occurrence of the basic schists, above described, are observable not only in the Nishiki-chô district but also throughout the whole extent of the eastern part of Yamaguchi Prefecture. Judging from these occurrence and nature of the basic schists on the field, it may be inferred that the basic schist masses in question would have been derived from sills or laccoliths of diabasic or gabbroic composition intruded concordantly or subconcordantly into sediments.

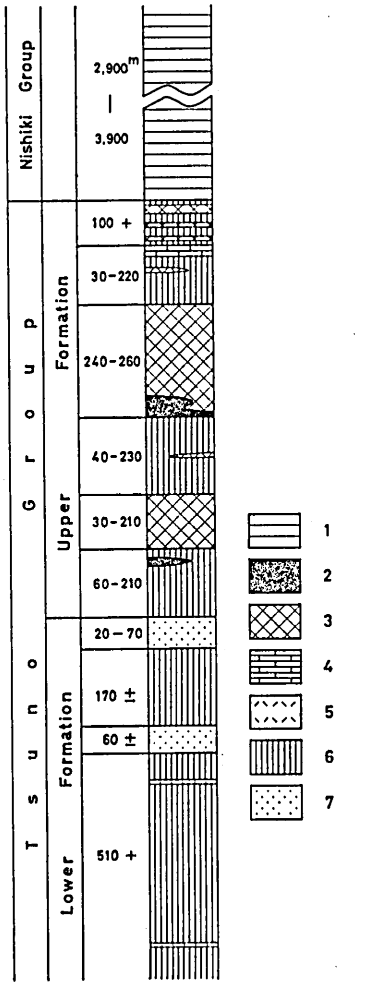

FIG. 2. Generalized columnar section of the Nishiki and Tsuno Groups of the Nishiki-chô district.
1: Nishiki Group, 2: Ultramafic rocks, 3: Basic schists, 4: Calcareous schists, 5: Siliceous schists, 6: Pelitic schists, 7: Psammitic schists.

C. CLASSIFICATION AND METAMORPHISM OF BASIC SCHISTS

Detailed examination on the field occurrence, hand specimens, thin sections and the chemical composition has revealed the existence of two kinds of basic schists among the Tsuno Group of the Nishiki-chô district.

In addition to the field observation of the basic schists above mentioned, more close relation between these two kinds of the basic schists can be afforded by observing the drill cores. The color of the basic schists is generally very pale-green at the contact zone of basic and pelitic schists, and the greenish tint gradually increases in going away from the contact, finally becoming green to dark green. The change is gradual. The thickness of the pale-green zone is about 2 m, though, as will be mentioned later, the zone having abnormal composition attains from 6 to 8 m in thickness. Based on these facts, the basic schists in question are tentatively divided into two types, namely, type I and type II.

(1) Basic schists of type I: This type occupies most part of relatively large lenticular masses of basic schists in this district, and is characterized by green to dark-

green color, medium grain-size and massive nature. The rocks are almost completely recrystallized. Relic clinopyroxene is very rarely observed in the rocks on the highest horizon of the Tsuno Group. Clots of epidote are often found. The following metamorphic minerals are commonly observed; albite, chlorite, pumpellyite, epidote, actinolite, subcalcic hornblende and crossite. Calcite, quartz, white mica, stilpnomelane and opaque minerals occur as accessories.

(2) Basic schists of type II: This type occurs in the peripheral parts of large lenticular masses of basic schists or forms thin layers. The rocks are pale green, fine-grained and schistose. Recrystallization is almost complete but relic clinopyroxene is also rarely observed in the rocks on the highest horizon of the Tsuno Group. The recrystallized minerals are as follows; albite, chlorite, white mica, pumpellyite, epidote, actinolite and crossite. Calcite, quartz, stilpnomelane and opaque minerals occur as accessories. White mica is abundant in some rocks.

On the basis of distribution of characteristic metamorphic minerals, the present metamorphic terrain can be divided into three zones, as shown in Fig. 3. Metamorphic grade increases from zone A, through zone B, to zone C.

Zone A is characterized by the assemblage pumpellyite-chlorite in basic and psammitic rocks. No schistosity develops and recrystallization is incomplete in this zone. The Nishiki Group belongs to the zone A as a whole.

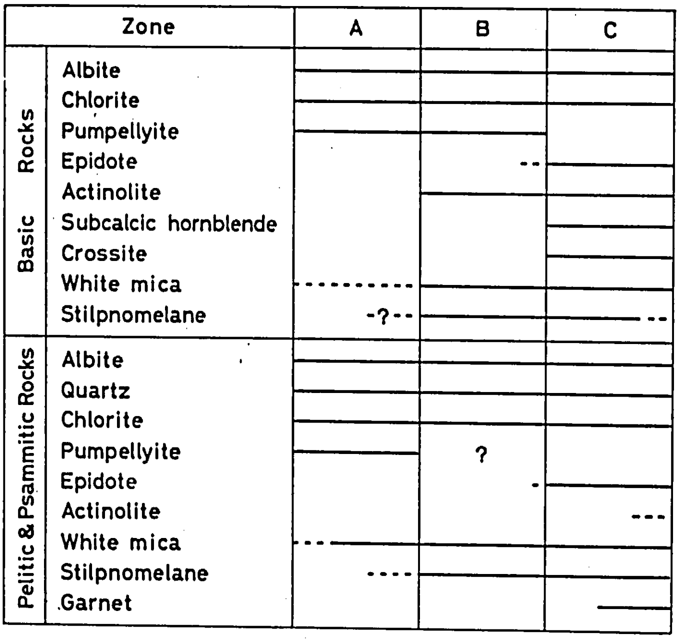

FIG. 3. Progressive mineralogical variations in regional metamorphism of the Nishiki-chô district. Broken line indicates the mineral being uncommon.

Zone B is characterized by the assemblage pumpellyite-actinolite in basic schists. Schistosity and lineation are well developed. Metamorphic recrystallization is almost complete, however, some relic clinopyroxenes are observed in a few basic schists which are located at the lowest grade part of this zone. Zone B practically coincides with the uppermost horizon in the upper formation of the Tsuno Group.

Zone C is characterized by the disappearance of pumpellyite and by the appearance of crossite and subcalcic hornblende in basic schists. Garnet also appears in pelitic and siliceous schists of this zone. This zone involves other lower stratigraphic horizons of the Tsuno Group.

The boundary surfaces between these metamorphic zones are nearly parallel to those of stratification, and the metamorphic grade increases from the upper to the lower horizon in the stratigraphic succession. The facies series of the regional metamorphism in the sense of MIYASHIRO (1961) of this district belongs to the high-pressure intermediate group (NISHIMURA, 1971), which characterizes other parts of the Sangun metamorphic belt.

Basic schists of the type I as well as the type II, as defined above, are observed both in zone B and zone C.

D. LOCALITY OF THE ANALYZED SPECIMENS

The most suitable outcrops for a detailed petrochemical study of the basic schists are found in the Deai–Miyanokushi area, where geology has been clarified in detail (Fig. 4). The two types of basic schists well crop out and their mutual relationship can be observed on the field. Large masses of basic schists at Deai and Miyanokushi form a large sill-like mass, nearly concordant with surrounding schist beds, having been subsequently buckled to form anticlinal and synclinal structures as shown in the figure. Furthermore, data from some drill holes of the Kawayama Mine are available in this area.

Therefore, the analyzed specimens in this paper have been collected in the Deai–Miyanokushi area. The localities of the specimens on the field and in the drill hole (No. 189) are shown in Figs. 4 and 5. Specimens of type I and type II are marked with solid and open circles, respectively.

Fig. 4. Geological map of the Deai-Miyanokushi area, showing the localities of the analyzed specimens.
1: Dyke rocks, 2: Rhyolitic pyroclastics, 3: Kuga Group, 4: Nishiki Group, 5-8: Tsuno Group (5: Ultramafic rocks, 6: Basic schists, 7: Calcareous schists, 8: Pelitic schists), 9: Fault and tectonic slide, 10: Successions of the analyzed specimens, 11: Type I basic schists, 12: Type II basic schists, 13: Location of the drill hole (No. 189).

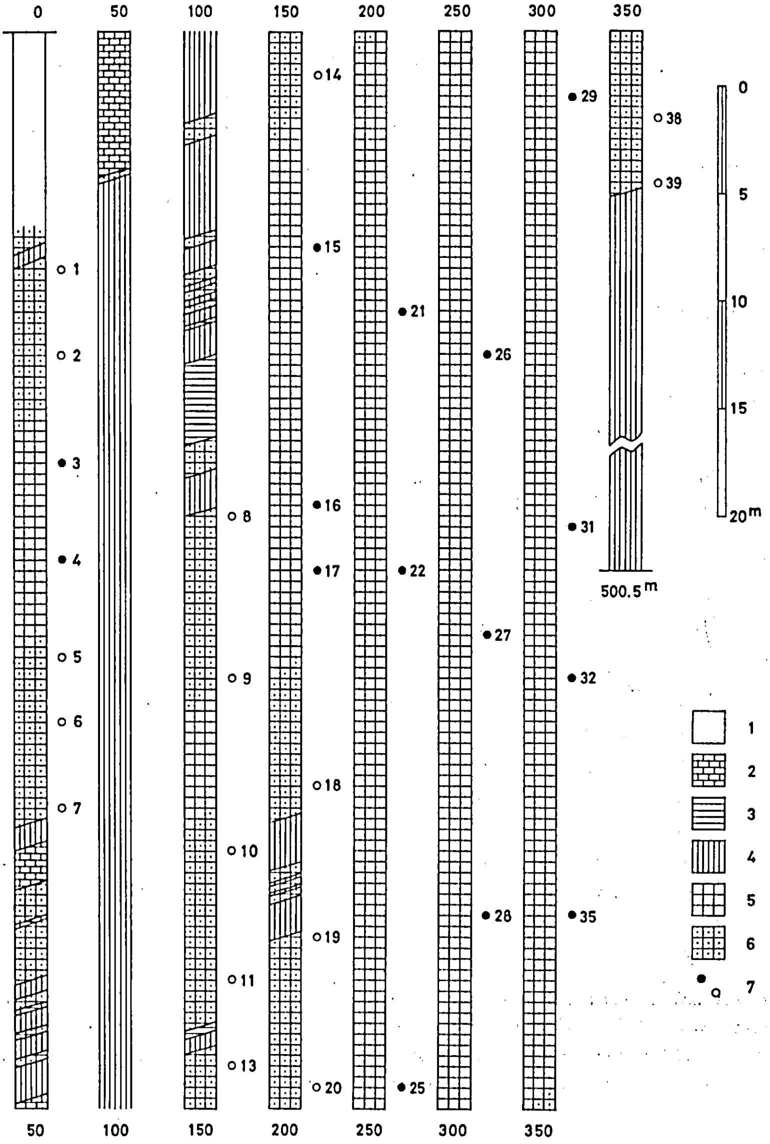

FIG. 5. Columnar section of the drill core (No. 189), showing the positions of the analyzed specimens.
1: Surface soil, 2: Calcareous schists, 3: Siliceous schists, 4: Pelitic schists, 5: Type I basic schists, 6: Type II basic schists, 7: Analyzed specimens.

III. PETROCHEMICAL STUDIES ON BASIC SCHISTS

A. METHOD AND RESULT OF CHEMICAL ANALYSIS

Basic schists in question are generally heterogeneous in appearance and in many cases contain segregation veins mainly composed of carbonate minerals. Therefore, veins as well as weathering parts have been eliminated by the hand-picking and powder specimens of homogeneous nature have been prepared to the amount of about 500 g. A part of the powder specimen, about 500 to 800 mg, was used for the chemical analysis.

A systematic method for silicate analysis using ion-exchage resins was devised by YOSHIMURA and WAKI (1957), and was modified by SHIBATA et al. (1960), ÔKI et al. (1962), HENMI and NUMANO (1966) and NUMANO (1966). The author adopted essentially the method of HENMI and NUMANO (1966) and NUMANO (1966), but slightly modified them.

TABLE 1. CHEMICAL ANALYSES OF SOME U.S. GEOLOGICAL SURVEY STANDARD SAMPLES

Standard sample	G-1		W-1		AGV-1		BCR-1	
Reference	This paper	FAIRBAIRN (1953)	This paper	FAIRBAIRN (1953)	This paper	FLANAGAN (1967)	This paper	FLANAGAN (1967)
Number of measurements	1	27-29	9	30-33	1	2	1	2
SiO_2	72.64	72.36 72.86*	52.58	52.34 52.69*	58.79	58.99	54.18	54.13
Al_2O_3	13.79	14.44 13.94*	14.73	15.07 14.72*	16.90	17.14	13.20	13.67
Fe_2O_3	0.85	0.93	1.43	1.50	4.28	4.36	3.46	3.21
FeO	0.74	0.99	8.69	8.71	2.04	2.06	8.84	9.08
MgO	0.41	0.39	6.64	6.63	1.50	1.50	3.45	3.49
CaO	1.48	1.41	10.84	10.96	5.04	4.90	6.99	6.91
Na_2O	3.34	3.25	2.19	2.00	4.24	4.23	3.29	3.29
K_2O	5.58	5.42	0.69	0.63	3.00	2.86	1.79	1.69
TiO_2	0.24	0.25	1.12	1.10	1.17	1.05	2.37	2.25
MnO	0.02	0.03	0.16	0.17	0.08	0.10	0.14	0.19
P_2O_5	0.07	0.09	0.14	0.13	0.53	0.49	0.38	0.35

* FAIRBAIRN (1953) showed that in the conventional analytical procedure, the unrecovered portion of SiO_2 remains with Al_2O_3. The preferred values for SiO_2 and Al_2O_3 were given in the Table by stars. It is noted that the values for Al_2O_3 obtained by the analytical method under consideration are identical with the preferred values for Al_2O_3 after FAIRBAIRN (1953).

The elements such as Na, K, Mg, Ca, Al, P, Ti, Mn and total Fe^{+3} are perfectly separated out by the use of ion-exchange resins. The estimations were carried out by chelate-titration for Mg, Ca, Al and total Fe^{+3}, by argentimetry for Cl in NaCl and KCl and by the colorimetric method for P, Ti and Mn. Fe^{+2} amount was determined by permanganometry. The amounts of SiO_2 and H_2O were determined gravimetrically. The ignition loss is tentatively represented by H_2O (+).

The accuracy of the chemical analysis was repeatedly checked by analyzing some U. S. Geological Survey standard samples. Fairly satisfactory results have been obtained. The results are listed in Table 1.

B. CHEMICAL COMPOSITION OF BASIC SCHISTS

Sixty-eight specimens, consisting of 37 collected on the field and of 31 from the drill core of the Kawayama Mine (No. 189), have been analyzed. Forty-seven specimens belong to type I and 21 to type II. The results are shown in Tables 2 and 3.

H_2O content of the analyzed basic schists varies from 3 to 10 in weight percent. These figures show that the basic schists are richer in H_2O than common basic igneous rocks which include H_2O at about one percent. Although $FeO/(FeO+Fe_2O_3)$ ratios of basic schists vary from 0.30 to 0.95, low values are more abundant in basic schists than in basic igneous rocks. These features are common in basic metamorphic rocks, and have been considered to be related to the formation of hydrous minerals such as chlorite and amphiboles under the condition of high water as well as oxygen pressures during regional metamorphism.

In view of finding general character on the original bulk chemical composition of the basic schists of this district, variation diagrams have been made (Fig. 6), in which type I and type II of the basic schists are separately plotted with solid and open circles, respectively.

As seen from the figure, the SiO_2 content of type I ranges from 43 to 51 percent and the contents of other major oxides, plotted against SiO_2, are similar to those of common basic igneous rocks. The Na_2O content which ranges from 1.50 to 4.51 percent is fairly less than that of average spilites (SUNDIUS, 1930; VALLANCE, 1960). It was reported that there are considerable differences in the amounts of TiO_2 and Al_2O_3 of Cenozoic oceanic and circumoceanic basalts, and that the former contains more TiO_2 and less Al_2O_3 than the latter (CHAYES, 1964, 1965). Most contents of TiO_2 in type I show the intermediate value between oceanic and circumoceanic basalts, whereas most contents of Al_2O_3 are similar to those of oceanic basalts.

On the other hand, when the amounts of oxides of type II are compared with those of type I, Al_2O_3 and K_2O are distinctly abundant and Na_2O and TiO_2 slightly abundant, whereas MgO and CaO are relatively poor in type II. Although $(FeO+Fe_2O_3)$ (as FeO) is nearly the same, FeO generally is more abundant in type II than in type I (Tables 2 and 3).

The $MgO-(FeO+Fe_2O_3)-(Na_2O+K_2O)$ diagram is shown in Fig. 7. In the figure, type I and type II rocks are separated in the field from each other with some overlap.

Judging from these features (cf. also Fig. 13), the composition of type II basic schists is distinctly different from that of common basic igneous rocks.

TABLE 2. CHEMICAL COMPOSITIONS OF

Loc. & Suc.	Deai, A (W→E)								
Spec. No.	3927-13	6655-2	6655-3	38520-5	6655-4	3886-5	6655-6	6655-7	6655-15
Type	II	I	I	I	I	I	I	I	I
SiO_2	50.32	47.42	46.66	50.15	49.55	47.25	45.24	42.95	48.92
Al_2O_3	16.19	12.78	14.27	13.04	13.25	13.95	14.82	14.70	13.64
Fe_2O_3	0.87	2.86	5.62	5.79	6.04	7.32	5.98	3.26	4.63
FeO	12.09	8.37	8.54	7.07	5.85	7.32	6.50	7.34	6.81
MgO	3.95	6.25	6.68	6.40	6.54	5.06	5.88	5.04	6.26
CaO	1.24	7.88	8.29	7.24	9.04	7.71	8.96	11.53	9.12
Na_2O	0.27	1.80	3.16	4.15	4.16	3.67	3.14	2.67	2.88
K_2O	3.98	0.77	0.93	0.75	0.79	0.62	0.50	1.02	0.43
TiO_2	1.78	1.96	0.95	1.92	1.20	2.03	0.56	0.62	1.93
P_2O_5	0.18	0.14	0.18	0.12	0.17	0.13	0.13	0.16	0.22
MnO	0.45	0.29	0.30	0.05	0.23	0.21	0.32	0.25	0.17
H_2O+	7.22	9.37	4.03	3.42	3.02	3.87	7.40	9.66	4.14
H_2O-	1.36	0.52	0.39	0.43	0.21	0.51	0.56	0.49	0.36
Total	99.90	100.41	100.00	100.53	100.05	99.65	99.99	99.69	99.51

Norms (CIPW)

		3927-13	6655-2	6655-3	38520-5	6655-4	3886-5	6655-6	6655-7	6655-15
Q		16.83	6.55	—	0.48	—	1.56	—	—	4.09
or		23.38	4.45	2.23	4.45	4.45	3.90	2.78	6.12	2.78
ab		2.10	15.21	18.88	35.14	35.14	30.94	26.75	14.69	24.13
an		5.01	24.48	25.87	14.75	15.30	19.75	24.76	25.04	23.09
ne		—	—	—	—	—	—	—	4.26	—
c		9.69	—	—	—	—	—	—	—	—
di	wo	—	5.81	11.85	8.48	11.85	7.32	7.90	13.13	8.71
	en	—	3.31	6.63	5.82	8.64	5.02	5.02	7.03	5.82
	fs	—	2.24	4.75	1.98	2.11	1.72	2.37	5.67	2.24
hy	en	9.84	12.25	8.33	10.14	2.61	7.53	5.62	—	9.74
	fs	19.40	7.92	5.67	3.17	0.66	2.77	2.51	—	3.56
ol	fo	—	—	1.83	—	3.52	—	2.81	3.87	—
	fa	—	—	1.43	—	1.02	—	1.43	3.57	—
mt		1.16	4.17	6.25	8.34	8.80	10.65	8.57	4.63	6.71
il		3.34	3.79	0.91	3.64	2.28	3.79	1.06	1.21	3.64
hm		—	—	—	—	—	—	—	—	—
ap		0.44	0.43	0.27	0.27	0.40	0.30	0.30	0.37	0.50

Analyst: Y. NISHIMURA

Chemical Composition of Basic Schists from the Sangun Metamorphic Terrain

BASIC SCHISTS COLLECTED ON THE FIELD

Deai, B (S → N)					Deai, C (E → W)				
38513-6	6655-17	6655-18	381225-1	38729-11	6657-1	6657-2	6657-3	6657-4	391011-1
I	I	I	I	II	I	I	I	I	I
47.41	48.34	46.79	45.73	36.97	48.91	49.73	50.22	46.02	44.01
13.64	13.56	19.20	13.04	17.99	12.89	13.48	16.29	13.68	12.45
6.69	3.39	5.55	2.35	1.62	6.91	6.31	6.62	2.57	3.43
8.35	9.34	4.75	8.83	17.57	6.15	6.56	4.47	10.42	7.88
4.98	6.46	4.29	6.79	6.04	4.99	4.63	3.58	8.29	5.76
7.56	7.71	9.32	8.18	4.13	11.24	9.85	8.78	8.36	13.21
3.41	3.96	3.35	2.97	2.36	1.88	2.80	3.74	2.74	2.32
1.03	0.23	0.90	0.23	0.36	0.30	0.53	0.35	0.24	0.26
0.96	2.54	1.18	1.67	2.96	1.51	2.14	1.38	2.25	1.61
0.23	0.14	0.32	0.10	0.10	0.15	0.28	0.17	0.19	0.14
0.19	0.23	0.13	0.22	0.29	0.37	0.24	0.20	0.21	0.22
4.70	3.74	3.36	8.41	8.08	3.96	2.97	3.64	4.56	7.76
0.45	0.33	0.34	0.75	0.73	0.29	0.31	0.27	0.34	0.38
99.60	99.97	99.48	99.27	99.20	99.55	99.83	99.71	99.87	99.43

Norms (CIPW)

0.36	—	—	—	—	10.22	7.75	6.43	—	6.79
6.12	1.11	5.57	1.11	2.23	1.67	3.34	2.23	1.67	1.67
28.85	33.57	28.32	25.18	19.93	15.73	23.60	31.47	23.08	19.41
18.92	18.64	34.50	21.70	20.03	25.87	22.54	26.71	24.21	22.81
—	—	—	—	—	—	—	—	—	—
—	—	—	—	6.32	—	—	—	—	—
7.20	7.78	4.07	7.67	—	12.08	10.34	6.62	6.74	17.54
4.12	4.52	3.01	4.31	—	8.53	7.23	5.32	3.92	1.00
2.77	2.90	0.66	3.03	—	2.51	2.24	0.53	2.51	6.73
8.33	7.23	5.62	10.04	3.72	4.12	4.32	3.61	9.04	4.32
5.81	4.75	1.19	7.12	6.47	1.32	1.32	0.40	6.07	2.77
—	3.03	1.41	1.76	7.95	—	—	—	5.42	—
—	2.14	0.41	1.32	15.59	—	—	—	3.97	—
9.73	4.86	8.10	3.47	2.32	9.96	9.26	9.49	3.70	4.86
1.82	4.86	2.28	3.19	5.61	2.88	4.10	2.58	4.25	3.04
—	—	—	—	—	—	—	—	—	—
0.54	0.34	0.74	0.24	0.24	0.34	0.67	0.40	0.44	0.34

TABLE 2. (Continued)

Loc. & Suc.	Deai, D (N → S)					Deai, E (N → S)		
Spec. No.	381221-8	6655-12	6655-11	6655-13	3885-7	38730-1	6655-9	6656-2
Type	I	I	I	I	I	I	I	II
SiO_2	50.17	47.50	45.28	47.65	45.94	49.40	46.65	48.99
Al_2O_3	14.02	13.89	14.65	13.64	13.58	13.03	13.57	16.60
Fe_2O_3	10.16	6.17	2.45	3.16	2.80	2.48	4.33	0.77
FeO	4.49	6.88	9.33	8.41	10.28	9.81	8.82	12.61
MgO	4.34	3.82	8.26	6.27	6.78	6.28	7.07	4.63
CaO	5.76	9.68	10.18	10.01	8.30	8.66	11.11	1.72
Na_2O	3.75	4.44	1.72	3.19	2.71	2.64	2.21	2.89
K_2O	1.00	0.33	0.55	0.45	0.11	0.27	0.42	1.47
TiO_2	1.70	2.22	1.70	2.33	2.28	1.24	0.46	1.79
P_2O_5	0.14	0.22	0.15	0.19	0.19	0.20	0.12	0.18
MnO	0.24	0.22	0.21	0.13	0.44	0.22	0.23	0.29
H_2O+	3.36	4.06	4.84	3.97	5.69	5.11	4.20	6.67
H_2O-	0.34	0.41	0.62	0.48	0.75	0.81	0.43	1.09
Total	99.47	99.84	99.94	99.88	99.85	100.15	99.62	99.70
Norms (CIPW)								
Q	7.75	—	—	—	—	3.00	—	6.91
or	6.12	2.23	3.34	2.78	0.56	1.67	2.23	8.91
ab	31.99	36.19	14.69	26.75	23.08	22.55	18.88	24.65
an	18.36	16.69	30.60	21.70	24.48	22.81	25.87	7.51
ne	—	0.85	—	—	—	—	—	—
c	—	—	—	—	—	—	—	7.44
di wo	3.95	12.55	7.78	11.15	6.51	7.90	11.85	—
en	3.41	8.13	4.52	6.63	3.51	4.02	6.63	—
fs	—	3.56	2.90	3.96	2.77	3.69	4.75	—
hy en	7.43	—	10.74	6.13	12.45	11.65	8.33	11.55
fs	—	—	6.60	3.56	10.03	10.56	5.67	20.19
ol fo	—	0.99	3.73	2.04	0.63	—	1.83	—
fa	—	0.51	2.55	1.32	0.51	—	1.43	—
mt	10.19	9.03	3.47	4.63	4.17	3.70	6.25	1.16
il	3.19	4.25	3.19	4.40	4.40	2.43	0.91	3.34
hm	3.19	—	—	—	—	—	—	—
ap	0.34	0.50	0.50	0.44	0.44	0.47	0.27	0.44

Analyst: Y. NISHIMURA

Miyanokushi, F (N→S)		Miyanokushi, G (W→E)						Miyanokushi, H (N→S)	
6656-4	6656-5	38729-1	6656-8	6656-9	6656-10	6656-16	6656-17	661019-2	661019-4
II	II	I	I	I	I	I	I	I	I
52.27	43.19	44.41	46.27	48.40	48.77	47.99	47.17	48.57	45.03
16.97	19.13	16.08	15.38	12.98	13.83	14.09	13.06	12.75	14.50
1.01	1.62	4.98	9.72	5.77	6.80	3.33	2.86	2.58	4.76
10.00	14.00	8.00	5.24	7.90	7.96	8.05	9.19	9.59	8.24
1.80	4.72	6.93	4.84	5.57	5.41	7.18	8.20	7.57	6.74
3.74	2.65	7.34	5.72	8.89	6.41	10.54	10.31	7.77	9.41
5.58	3.32	2.49	2.97	2.41	4.51	2.61	2.23	3.31	2.76
1.10	2.53	0.46	1.72	0.63	0.90	0.24	0.21	1.01	0.93
2.88	2.50	3.28	2.04	0.98	2.14	1.44	1.45	1.81	2.04
0.59	0.19	0.49	0.19	0.14	0.08	0.14	0.16	0.13	0.18
0.35	0.36	0.14	0.10	0.28	0.15	0.19	0.18	0.19	0.19
3.71	6.04	5.26	5.01	5.33	3.44	3.47	4.32	3.62	4.87
0.33	0.25	0.24	0.33	0.30	0.29	0.21	0.27	0.47	0.22
100.33	100.50	100.10	99.53	99.58	100.69	99.48	99.61	99.39	99.87
Norms (CIPW)									
0.06	—	1.44	4.27	5.34	—	—	—	—	—
6.68	15.03	2.78	10.02	3.90	5.57	1.67	1.11	6.12	5.57
47.20	28.32	20.98	25.18	20.45	38.29	22.03	18.88	27.80	23.60
15.30	11.96	31.44	23.65	22.54	14.75	25.87	25.04	16.97	24.21
—	—	—	—	—	—	—	—	—	—
0.92	6.53	—	—	—	—	—	—	—	—
—	—	0.70	1.51	8.71	6.85	10.69	10.46	8.71	8.95
—	—	0.50	1.31	5.12	4.52	6.43	6.13	4.92	5.62
—	—	0.13	—	3.17	1.85	3.69	3.83	3.43	2.77
4.52	0.80	16.77	10.74	8.74	4.72	11.05	12.75	6.23	2.21
13.46	1.32	5.28	—	5.54	1.98	6.07	7.78	4.22	1.06
—	7.67	—	—	—	2.96	0.28	1.06	5.42	6.26
—	15.18	—	—	—	1.43	0.20	0.71	3.97	3.36
1.39	2.32	7.18	11.11	8.34	9.96	4.86	4.17	3.70	6.95
5.46	4.70	6.22	3.95	1.82	4.10	2.73	2.73	3.49	3.95
—	—	—	2.08	—	—	—	—	—	—
1.34	0.44	1.18	0.44	0.34	0.20	0.34	0.37	0.30	0.44

TABLE 3. CHEMICAL COMPOSITIONS OF BASIC SCHISTS COLLECTED

Spec. No.		1	2	3	4	5	6	7
Type		II	II	I	I	II	II	II
SiO_2		48.11	49.86	45.11	39.69	49.58	50.25	49.44
Al_2O_3		17.03	16.46	13.28	16.21	16.14	16.49	17.39
Fe_2O_3		1.11	4.44	1.97	6.26	6.21	8.27	1.46
FeO		9.81	6.46	8.44	9.69	5.42	4.03	10.94
MgO		4.38	3.70	5.70	8.70	4.19	2.61	1.75
CaO		4.95	6.48	9.34	4.69	5.36	3.78	4.25
Na_2O		3.87	4.91	2.93	3.26	5.84	5.48	6.05
K_2O		1.48	0.41	0.19	1.11	0.79	2.19	0.90
TiO_2		1.73	1.97	3.85	3.02	2.58	2.44	2.76
P_2O_5		0.21	0.55	0.43	0.47	0.31	0.68	0.60
MnO		0.28	0.22	0.23	0.47	0.16	0.19	0.20
H_2O+		6.45	3.86	8.05	6.15	3.53	3.70	4.32
H_2O-		0.24	0.27	0.21	0.21	0.15	0.14	0.29
Total		99.65	99.59	99.73	99.93	100.26	100.25	100.35
Norms (CIPW)								
Q		—	1.08	1.02	—	—	0.06	—
or		8.91	2.23	1.11	6.68	4.45	12.80	5.57
ab		32.52	41.43	24.65	25.70	48.78	46.15	47.73
an		23.37	21.70	22.54	20.59	15.58	14.19	17.53
ne		—	—	—	1.14	0.28	—	1.99
c		0.51	—	—	2.04	—	—	—
di	wo	—	3.02	8.95	—	3.83	0.23	0.12
	en	—	1.81	5.42	—	3.11	0.20	—
	fs	—	1.06	3.03	—	0.26	—	0.13
hy	en	5.42	7.43	8.74	—	—	6.33	—
	fs	7.26	4.22	4.88	—	—	—	—
ol	fo	3.87	—	—	15.20	5.14	—	2.96
	fa	5.81	—	—	6.62	0.41	—	11.21
mt		1.62	6.48	2.78	9.03	9.03	6.48	2.08
il		3.34	3.79	7.28	5.77	4.86	4.70	5.31
hm		—	—	—	—	—	3.83	—
ap		0.50	1.31	1.01	1.11	0.74	1.61	1.34

Analyst: Y. NISHIMURA

Chemical Composition of Basic Schists from the Sangun Metamorphic Terrain

FROM THE DRILL CORE SPECIMENS (No. 189)

8	9	10	11	13	14	15	16	17
II	II	II	II	II	II	I	I	I
44.80	40.50	48.10	40.11	43.41	38.59	44.42	47.58	43.76
17.34	18.83	17.22	18.74	13.82	14.95	13.24	14.41	16.29
1.05	5.54	6.80	7.92	1.60	7.00	5.77	5.02	4.69
13.77	8.28	7.63	7.22	12.05	12.35	9.29	7.99	8.96
2.33	2.39	1.75	2.67	5.10	4.04	6.88	5.75	5.70
4.61	9.70	4.05	7.93	9.04	10.06	8.97	8.63	9.16
2.11	2.17	5.44	1.39	1.79	1.46	2.95	3.78	2.56
2.93	2.92	1.76	4.79	0.41	0.68	0.29	0.54	0.58
2.91	4.03	2.63	3.58	2.14	3.38	2.04	1.93	2.04
0.84	0.61	0.50	0.56	0.23	0.25	0.18	0.25	0.21
0.29	0.27	0.18	0.23	0.24	0.40	0.26	0.20	0.22
6.58	4.58	3.38	4.50	9.58	6.18	4.81	3.72	5.51
0.16	0.14	0.14	0.20	0.20	0.49	0.29	0.19	0.22
99.72	99.96	99.58	99.84	99.61	99.83	99.39	99.99	99.90

Norms (CIPW)

1.02	—	—	—	0.30	—	—	—	—
17.26	17.26	10.58	28.39	2.23	3.90	1.67	3.34	3.34
17.83	5.77	45.63	4.20	15.21	12.59	25.18	31.99	21.50
17.81	33.11	17.25	30.88	28.66	32.27	21.98	20.59	31.44
—	6.82	0.28	3.98	—	—	—	—	—
4.18	—	—	—	—	—	—	—	—
—	4.76	—	2.09	6.16	6.74	8.95	8.71	5.34
—	2.61	—	1.51	2.61	3.01	5.42	5.32	3.01
—	1.98	—	0.40	3.56	3.69	3.03	2.90	2.11
5.82	—	—	—	10.04	4.22	5.52	4.02	5.82
20.19	—	—	—	14.12	5.28	2.90	2.24	3.96
—	2.32	3.03	3.59	—	1.97	4.36	3.52	3.73
—	1.94	3.36	0.51	—	2.45	2.65	2.04	2.75
1.62	8.10	9.96	11.58	2.32	10.19	8.34	7.18	6.71
5.46	7.59	5.01	6.83	4.10	6.37	3.95	3.64	3.95
—	—	—	—	—	—	—	—	—
2.02	1.45	1.18	1.31	0.54	0.61	0.44	0.61	0.50

TABLE 3. (Continued)

Spec. No.	18	19	20	21	22	25	26
Type	II	II	II	I	I	I	I
SiO_2	43.34	51.22	43.52	47.07	45.83	49.03	50.15
Al_2O_3	14.42	12.30	13.90	14.70	14.02	14.31	15.01
Fe_2O_3	2.49	0.80	7.34	3.44	5.37	2.65	3.55
FeO	13.37	9.98	8.90	7.19	9.59	8.19	6.62
MgO	5.96	5.79	5.26	5.90	7.42	8.13	5.51
CaO	8.16	6.80	7.85	9.71	7.37	6.31	9.54
Na_2O	2.22	0.13	3.22	3.64	1.50	4.05	4.23
K_2O	0.45	2.19	1.33	0.54	0.23	0.29	0.14
TiO_2	2.35	1.04	3.34	1.47	2.56	1.45	1.82
P_2O_5	0.24	0.11	0.43	0.17	0.23	0.11	0.15
MnO	0.33	0.35	0.28	0.19	0.22	0.19	0.17
H_2O+	5.91	9.45	4.33	5.61	5.69	4.71	2.83
H_2O-	0.66	0.21	0.25	0.21	0.22	0.26	0.12
Total	99.90	100.37	99.95	99.84	100.25	99.68	99.84

Norms (CIPW)

Q	—	13.10	—	—	6.91	—	—
or	2.78	12.80	7.79	3.34	1.11	1.67	0.56
ab	18.88	1.05	27.27	30.42	12.59	34.09	35.66
an	27.82	26.71	19.48	21.98	31.16	20.03	21.70
ne	—	—	—	0.28	—	—	—
c	—	—	—	—	—	—	—
di wo	4.76	2.56	7.09	10.46	1.63	4.41	10.34
di en	2.11	1.20	4.72	6.32	1.00	2.71	6.63
di fs	2.64	1.32	1.85	3.56	0.53	1.45	3.03
hy en	6.73	13.25	1.81	—	17.47	9.24	5.62
hy fs	8.71	15.31	0.66	—	8.71	5.01	2.77
ol fo	4.22	—	4.57	5.84	—	5.84	1.06
ol fa	6.11	—	2.14	3.67	—	3.36	0.51
mt	3.70	1.16	10.65	5.09	7.87	3.94	5.09
il	4.40	1.97	6.37	2.73	4.86	2.73	3.49
hm	—	—	—	—	—	—	—
ap	0.57	0.27	1.01	0.40	0.54	0.27	0.34

Analyst: Y. NISHIMURA

27	28	29	31	32	35	38	39
I	I	I	I	I	I	II	II
45.45	48.60	48.32	46.30	50.68	46.15	45.27	46.78
16.97	12.72	13.96	17.96	15.42	14.47	15.37	13.71
6.95	3.88	3.97	6.92	2.09	5.11	3.76	1.57
5.92	7.59	7.98	5.25	6.85	7.22	9.57	11.06
4.04	5.98	6.02	4.12	6.84	6.31	4.91	5.91
9.86	11.10	9.99	6.79	7.25	9.03	8.39	4.82
2.31	3.52	3.39	4.14	3.14	2.78	3.59	3.62
1.85	0.46	0.32	1.54	2.48	1.16	0.53	0.73
1.74	1.46	1.91	2.34	1.36	1.82	2.21	2.22
0.22	0.15	0.21	0.60	0.13	0.17	0.22	0.21
0.26	0.18	0.11	0.17	0.15	0.23	0.33	0.15
4.23	3.83	3.46	3.60	3.42	5.20	5.38	8.43
0.21	0.13	0.15	0.09	0.15	0.23	0.21	0.36
100.01	99.60	99.79	99.82	99.96	99.88	99.74	99.57

Norms (CIPW)

0.84	—	—	—	—	—	—	—
11.13	2.78	1.67	8.91	14.47	6.68	3.34	4.45
19.41	29.90	28.85	35.14	26.75	23.60	30.42	30.42
30.33	17.53	21.98	25.87	20.59	23.65	24.21	18.92
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
7.20	15.33	10.92	1.86	6.04	8.36	6.74	1.51
5.22	9.14	6.63	1.51	3.72	5.52	3.41	0.70
1.32	5.41	3.69	0.13	1.98	2.24	3.17	0.79
4.82	0.80	7.03	2.01	5.22	7.03	0.50	10.44
1.32	0.40	4.09	0.13	2.77	2.90	0.40	11.08
—	3.45	0.91	4.71	5.70	2.18	5.84	2.53
—	2.34	0.51	0.10	3.16	0.92	6.01	2.85
10.19	5.56	5.79	9.96	3.01	7.41	5.56	2.32
3.34	2.73	3.64	4.40	2.58	3.49	4.25	4.25
—	—	—	—	—	—	—	—
0.50	0.34	0.50	1.34	0.57	0.77	0.50	0.50

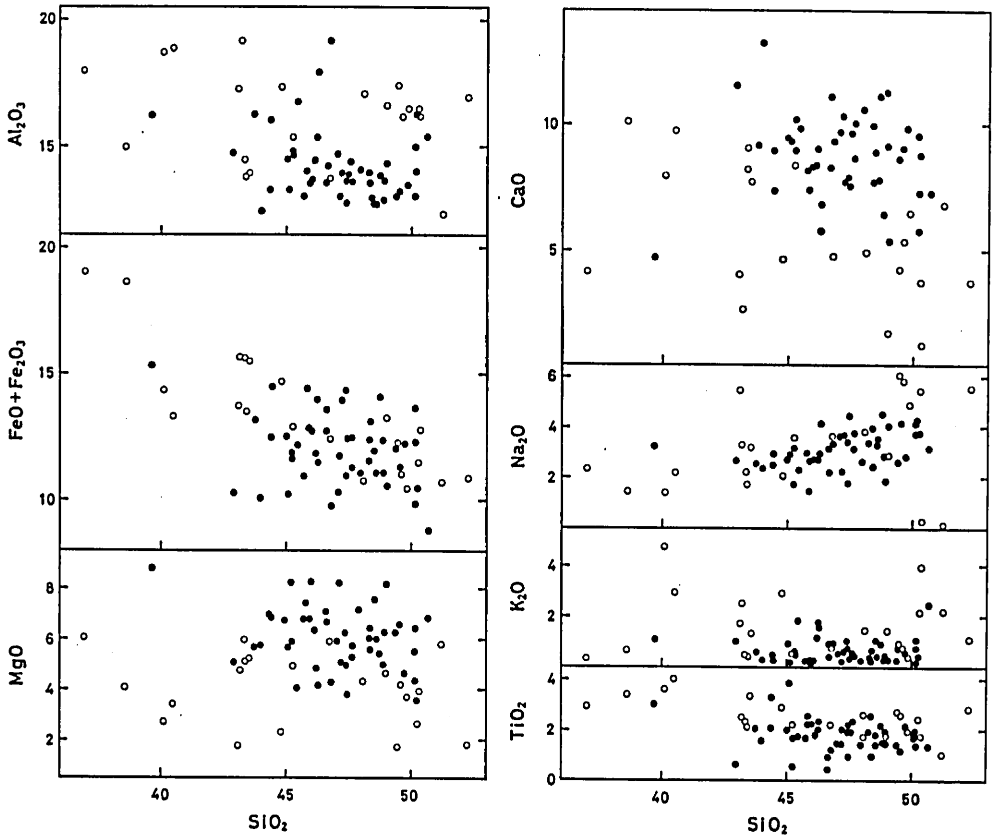

Fig. 6. Variation diagrams for the oxide components of basic schists from the Nishiki-chô district.

Solid circles: Type I basic schists, Open circles: Type II basic schists.

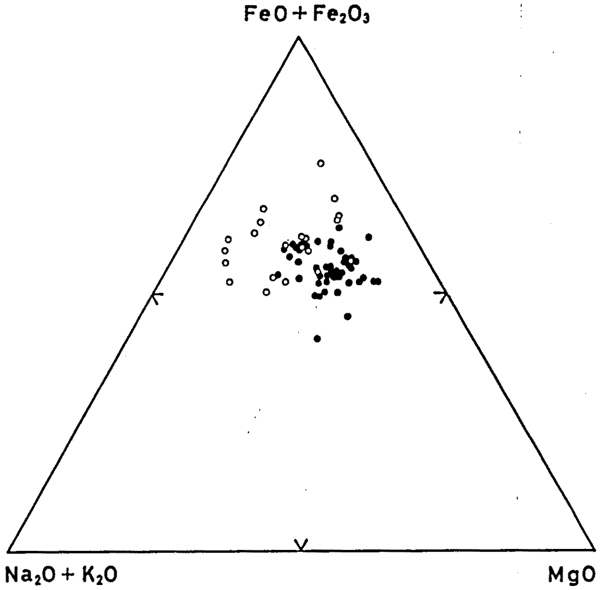

FIG. 7. M F A diagram showing distribution of basic schists belonging to type I (solid circles) and type II (open circles).

C. NATURE OF THE MOST PERIPHERAL ZONE OF THE BASIC MASSES

For considering the relationship between the two types of basic schists chemically (as well as mineralogically), detailed analyses have been tried on the specimens selected from a drill core of a basic schist mass, about 25 m thick, intervened between two pelitic schist beds. Seven specimens were picked up successively at intervals of 4 to 5 m from the drill core. Three of these, namely, Nos. 1, 6 and 7, are typical pale-green schistose rocks, and the other two, Nos. 3 and 4, are common dark-green massive rocks, while the rest two, Nos. 2 and 5, are transitional in appearance (Fig. 5). The five specimens, Nos. 1, 2, 5, 6 and 7, belong to type II and the other two, Nos. 3 and 4, to type I.

The analyzed data are plotted on the $(MgO+CaO)-(Al_2O_3+K_2O)$ diagram, in which the points in question are linked by tie-lines with arrows (Fig. 8). The arrows represent the order from the upper to the lower horizon. The cross mark on the diagram represents the average composition of 31 Paleozoic pelites from the Inner Zone of Southwest Japan after MIYASHIRO and HARAMURA (1962).

As seen from Fig. 8, the more the core is approached from the margin, the more increases the content of $(MgO+CaO)$ and decreases that of $(Al_2O_3+K_2O)$. When viewed in detail, three specimens, Nos. 1, 6 and 7, collected from the marginal zone, are closely situated toward the average pelitic rock than toward basalts, while Nos. 3 and 4, representing the core part, are basaltic, the rest, Nos. 2 and 5, being transitional. That is in harmony with other features mentioned above.

Furthermore, the rocks of type II are chemically so peculiar that they cannot be regarded as derived isochemically from any usual igneous rocks.

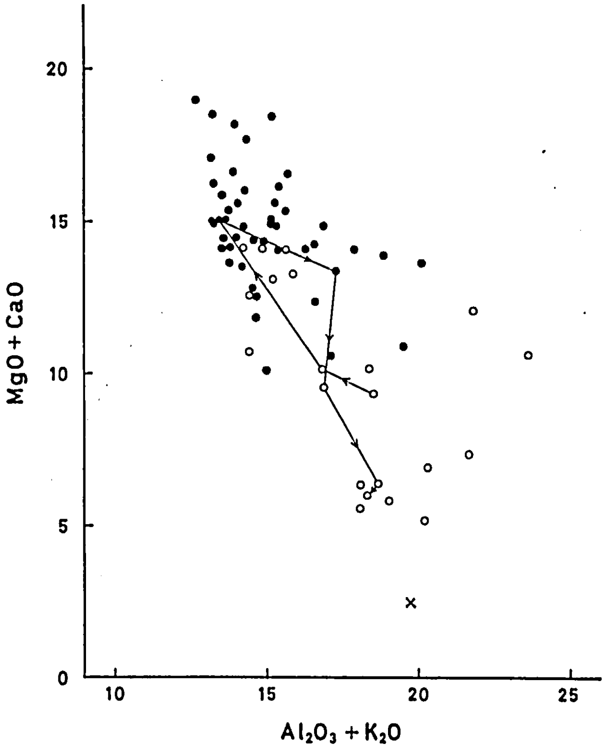

FIG. 8. $(MgO+CaO)$-$(Al_2O_3+K_2O)$ diagram of basic schists.
Solid circles: Type I basic schists, Open circles: Type II basic schists. Points linked by tie-lines with arrows indicate the basic schists selected from a basic schist mass about 25 m thick (see the text). The arrows show the descending order of the horizons of the specimens. The cross mark represents the average composition of 31 Paleozoic pelites from the Inner Zone of Southwest Japan after MIYASHIRO and HARAMURA (1962).

Based on these features, such as chemistry, fabrics and occurrence as well, one cannot help ascribing these peculiarities to the effect of contamination between the basic rock as represented by type I and the pelitic one, although there remains a question: when and how the contamination occurred. Was there any hybrid zone formed when the original basaltic or gabbroic sill-like mass was intruded before regional metamorphism? Or, did any kind of selective migration of components occur during regional metamorphism? The latter would correspond to the "greenstonization" of pelitic rocks at the peripheral zone of green rocks, as suggested by KOJIMA (1948).

The zone of contamination ranges several to 8 m in thickness from the boundary to typical pelitic rocks.

All analyzed data of basic schists, both type I and type II, are plotted on the same diagram (Fig. 8). The figure of distribution of the points shows the same tendency as described above, namely, type II rocks tend to be richer in alumina and potash, while poorer in magnesia and lime. It must be noted that most of basic schists occurring as thin layers belong to type II, namely, chemically identical with those of peripheral parts of larger masses of basic schists. Based on the above discussion, these thin layers of basic schists would either represents wholly contaminated tapered parts of relatively large basic masses, or "greenstonized" pelitic rocks affected by adjacent green rocks, probably lying nearly on the same horizon.

In the following sections, accordingly, type II rocks have to be set aside, when examining the original nature of the basic schists of this district.

D. Compositional Variation within a Basic Mass

As the composition of type I rocks shows a certain degree of variation, it can be inferred on the basis of compositional variation of type I rocks to determine the suite of igneous rocks which may belong to the same genetic origin (Fig. 6).

With a view to examine the compositional variation in a larger mass, specimens of type I have been collected without selection from the upper to the lower position at intervals of several ten meters successively in almost all the outcrops of the Deai-Miyanokushi mass. The locality is shown in Fig. 4. At the Deai area, specimens

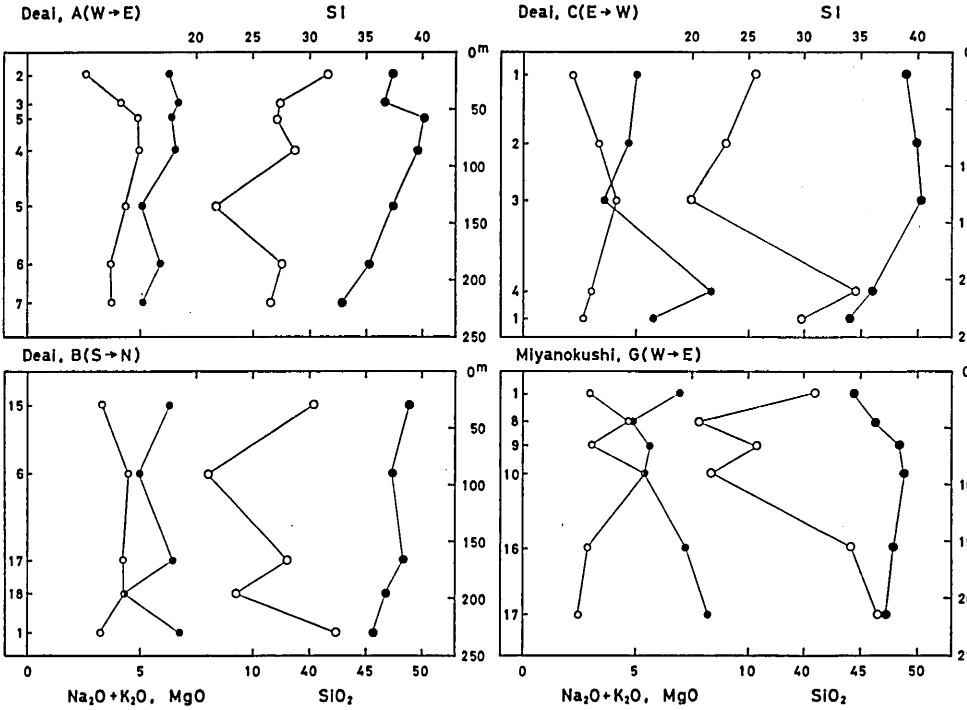

FIG. 9. Chemical variation within the Deai-Miyanokushi mass, showing the variation of (Na_2O+K_2O), MgO, SiO_2 and SI against the horizon within the sill.
Small open circles: (Na_2O+K_2O), Small solid circles: MgO, Large solid circles: SiO_2, Large open circles: $SI=MgO\times100/MgO+FeO+Fe_2O_3+Na_2O+K_2O$.

along four successions, namely, A(W→E), B(S→N), C(E→W) and D(N→S), have been collected. The succession D(N→S), however, was discarded in this examination, because the situation of each specimen cannot be exactly determined in the sill. Situations of each specimen in other successions, including that of the Miyanokushi area, namely, G(W→E), have been projected, based on the average thickness of 250 m of the sill, and the variations of each oxide and each solidification index (SI $=MgO \times 100/MgO+FeO+Fe_2O_3+Na_2O+K_2O$) as defined by KUNO et al. (1957) have been examined within the sill.

Fig. 9 shows the variations of (Na_2O+K_2O), MgO, SiO_2 and SI against the horizon within a sill. It can be perceived in the figure that the oxides and the solidification index vary from both the upper and the lower parts to the central part in the sill in a relatively consistent fashion throughout four successions. That is, the amounts of SiO_2 and of (Na_2O+K_2O) increase from the lower to the central part and decrease in proceeding to the upper part. On the contrary, the amounts of MgO and the solidification index decrease both from the lower and the upper parts to the central region. Especially, the solidification index shows a remarkable variation. For the specimens picked out from a drill core of the Kawayama Mine (No. 189), when plotted by the same method, the trend of variations is nearly the same (Fig. 10).

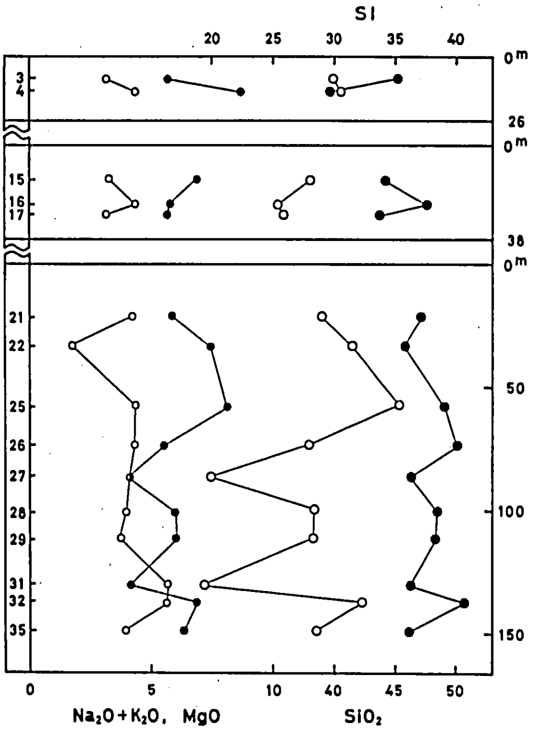

FIG. 10. Chemical variation in the drill core specimens for (Na_2O+K_2O), MgO, SiO_2 and SI. Symboles are identical with those of Figure 9.

Above facts suggest that the nature of vertical variation of chemical composition is nearly the same throughout the sill, and that no significant difference can be detected laterally. Therefore, on account of visualizing the general feature of compositional variation in the vertical direction of the sill, the sill was divided into five layers each 50 m thick, and the chemical composition of the specimens was averaged with respect to each layer. The average compositional variations against the height are shown in Fig. 11. The figure clearly represents the regularity of trend of compositional variation as mentioned above.

The average trend of chemical composition of the sill has also been plotted on the $MgO-(FeO+Fe_2O_3)-(Na_2O+K_2O)$ diagram, in

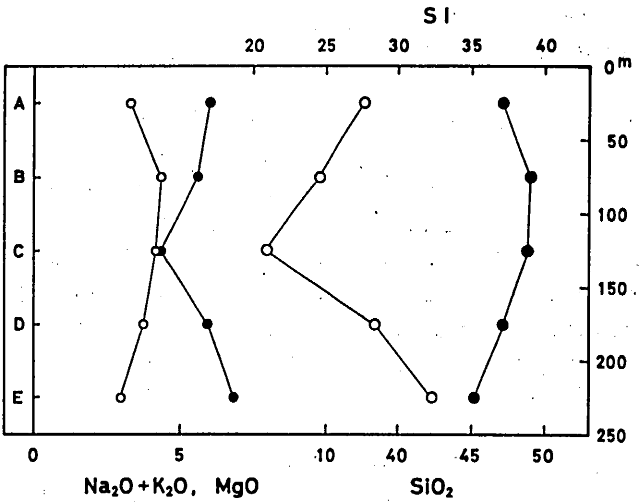

FIG. 11. Chemical variation for (Na_2O+K_2O), MgO, SiO_2 and SI of the Deai-Miyanokushi mass, based on the average values. Symboles are identical with those of Figure 9.

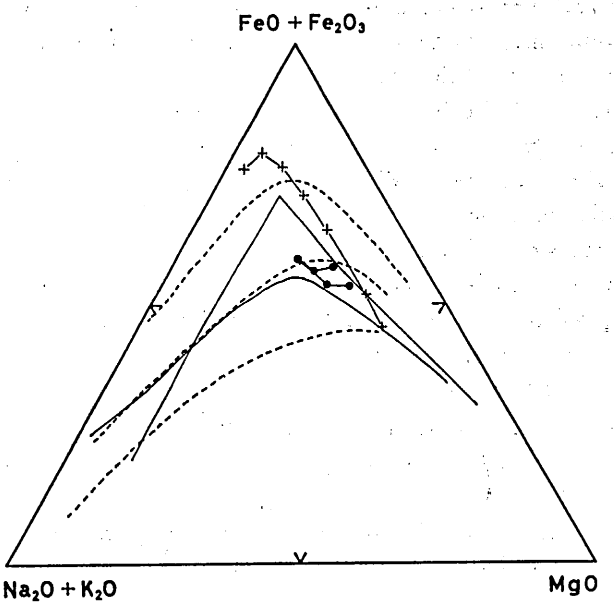

FIG. 12. M F A diagram showing average chemical composition of the type I basic rocks.

Solid circles linked by solid line: Average compositions of basic schists from the Nishiki-chô district.

Crosses linked by solid line: Compositions of successive liquids of the Skaergaard intrusion (WAGER, 1960).

Solid lines: Average trend lines of the Hawaiian tholeiitic and alkalic suites (MACDONALD and KATSURA, 1964).

Dotted lines: Fields for aphyric rocks of the pigionitic and hypersthenic rock series from the Izu-Hakone region (KUNO, 1968).

which some trend lines are shown for comparison (Fig. 12). The trend of the basic sill in this district is very narrow but is rather similar to that of Hawaiian alkalic rocks.

If one tries to interprete these regular features of chemical variation of the basic sills on the basis of differentiation of a gabbroic magma intruded before regional metamorphism, the differentiation should have proceeded both from the upper and the lower marginal layers to the central layer, because the formers are poorer in alkali and silica, while the latter shows lower values of magnesia and SI. But, this interpretation may not be unequivocal, because a certain kind of mobility of components should be expected, as discussed above (see III-C). Along this line of interpretation, such changes as migration of magnesia from the core to the margin and of alkali inward from the margin would be assumed.

E. IGNEOUS ROCK SERIES OF BASIC ROCKS

It is an important, though difficult, problem to determine to what kind of igneous rock series the original rocks of such metamorphic rocks as greenschists or glaucophane schists belong under geosynclinal conditions before regional metamorphism. Two ways of approach are conceivable in this investigation. The one is to examine the bulk chemical composition of these rocks and the other is to examine relic minerals such as pyroxenes (BANNO, 1964; HASHIMOTO, 1968).

In the examination of the bulk chemical composition, several methods have been applied to visualize petrochemical characters of the basic metamorphic rocks. Many authors have usually calculated CIPW norms of rocks. However, in the present case, original FeO could have been oxidized to change to Fe_2O_3 partly at least during regional metamorphism. If it be the case, the reduction in FeO should affect the values of normative diopside, hypersthene, olivin and quartz, and the norm cannot represent the original composition. Accordingly, the division of basaltic rocks on the basis of their normative composition as given by YODER and TILLEY (1962) is not applicable to the basic schists in question.

The diagram of total alkali-silica relation has been proved to be useful to illustrate the difference in chemical composition of the tholeiitic and alkalic rock series (KUNO, 1959; MACDONALD and KATSURA, 1964). The same diagram for basic schists in this district is shown in Fig. 13[1]. The straight line in the figure represents the boundary between the tholeiitic and alkalic fields in Hawaiian basaltic rocks after MACDONALD and KATSURA (1964). In the diagram, points plotted for all analyzed type I basic schists are distributed on both fields, but the majority of them fall on the field of the alkalic rocks.

HASHIMOTO (1964) stated that SUGIMURA's silica index θ for volcanic rocks is suitably to be applicated to metamorphic rocks. The silica index is calculated from

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[1] For reference, data of type II are also plotted. The rocks of type II are more dispersed and more abundant in alkali content than those of type I.

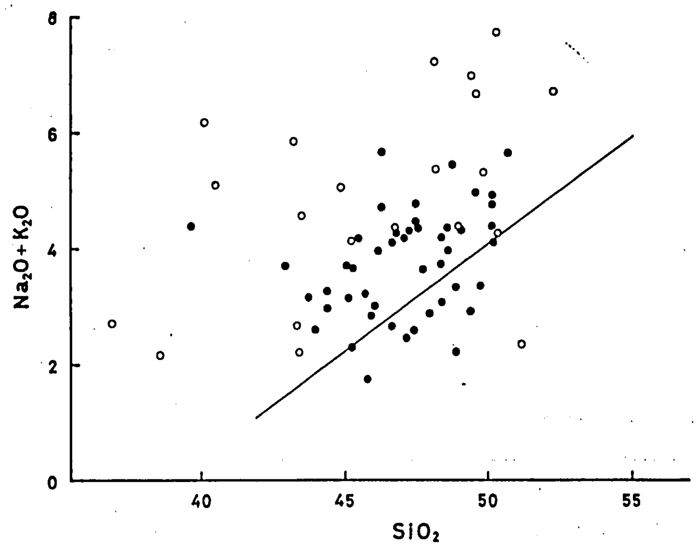

FIG. 13. Alkali-silica diagram for basic schists.
Solid circles: Type I basic schists, Open circles: Type II basic schists.
The straight line is the boundary between the tholeiitic and alkalic fields of the Hawaiian lavas after MACDONALD and KATSURA (1964).

the chemical composition of volcanic rock after the following formula:

$$\theta = SiO_2 - 47(Na_2O + K_2O)/Al_2O_3$$

where SiO_2 is expressed in weight percent, while for Na_2O, K_2O and Al_2O_3 their molecular proportions should be used (SUGIMURA, 1959, 1960). According to SUGIMURA, the index θ indicates how siliceous the parental magma of the volcanic rock is. The higher the index θ of a volcanic rock, the more siliceous (tholeiitic) its parental magma is. On the contrary, lower θ value indicates more alkalic parental magma. The index θ of the ordinary tholeiitic rocks is about 40, while that of the alkalic rocks is much smaller, 30 or less. The index θ of type I rocks in this district was calculated from the chemical composition adjusted to 100 percent excluding H_2O. It ranges from 39 to 21, as shown in Fig. 14, which corresponds to HASHIMOTO's Figure 1. As read from the figure, the values of θ vary within the range of the so-called "glaucophanitic metamorphic terrains" after HASHIMOTO, having the tendency to be more alkalic.

Some relic clinopyroxenes have been found in weakly recrystallized rocks both of type I and type II on the highest horizon of the Tsuno Group. Optical properties of these minerals are listed in Table 4. As these relic clinopyroxenes are generally colorless under the microscope, the effect of TiO_2 content on the optics can be disregarded. Thus, estimated chemical compositions from their optical properties can be plotted on the Di-Hd-Fs-En trapezoid (Fig. 15) using the diagrams of WINCHELL

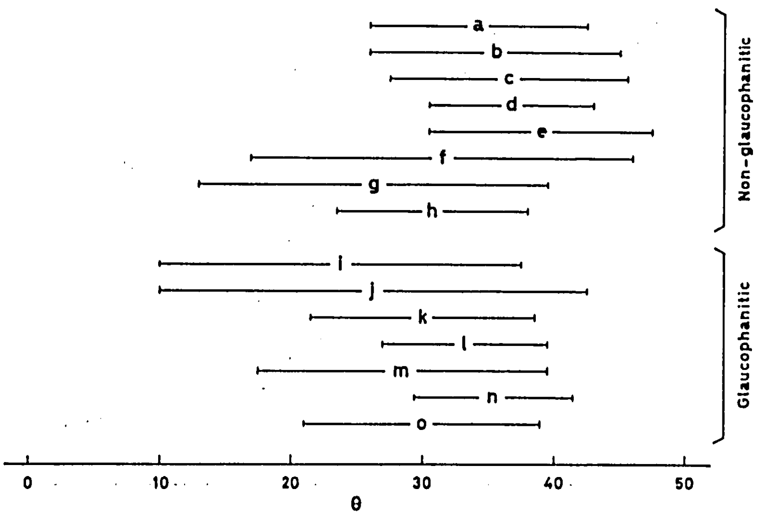

Fig. 14. Ranges of θ of basic rocks from various metamorphic terrains.
a-n: After Hashimoto (1964).
a-h: Non-glaucophanitic terrains (a: The central Abukuma Plateau, b: The southern Abukuma Plateau, c: The Misaka Series, d: The Grampian Highlands, e: The southeastern Australia, f: The Wakatipu region, g: The Sulitelma district, h: The Connemara district).
i-n: Glaucophanitic terrains (i: The Kanto Mountains, j: The Kamuikotan region, k: The Sambagawa belt, Shikoku, l: The Fukuoka district, m: Corsica, n: The Caracas region).
o: The Nishiki-chô district.

Table 4. Optical Properties of Relic Clinopyroxenes in Basic Schists

Specimen No.	α	β	γ	$2V_Z$	Host rock
65523-1	1.686	1.698	1.720	52°	Chlorite-actinolite-pumpellyite schist
69318-1	1.680	1.689	1.710	53°	Chlorite-actinolite-pumpellyite schist
69318-2	1.682	1.691	1.714	52°	Chlorite-actinolite-pumpellyite schist

and Winchell (1951, Fig. 289) and Deer et al. (1963, Fig. 41). The minerals are augite close to salite after the nomenclature of Poldervaart and Hess (1951). As discussed in the preceding pages, the type II rocks of abnormal composition are presumed to be contamination products, but the relic pyroxene can be regarded to represent the original nature of the rocks.

The clinopyroxenes of basic alkalic rocks show a relatively small variation in composition and the majority have a salite composition; the remainder lie in the augite field close to the boundary of salite and augite (Murray, 1954; Wilkinson, 1956, 1957; Kushiro, 1964). On the other hand, the clinopyroxenes of tholeiitic rocks are generally poorer in calcium and occupy more outside field than those of alkalic rocks

(BROWN, 1957; BROWN and VINCENT, 1963; ATKINS, 1969 and others). Some trends of clinopyroxene crystallization are also plotted in Fig. 15 for comparison. The clinopyroxenes of basic schists in the Nishiki-chô district are thus considered to be clinopyroxenes characteristic of basic alkalic rocks.

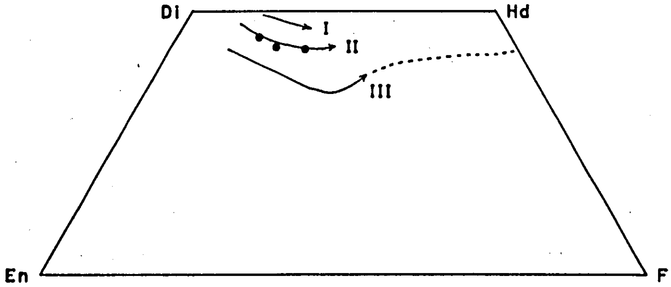

FIG. 15. Chemical compositions of relic clinopyroxenes in basic schists compared with some trends of clinopyroxene crystallization.
Solid circles: Clinopyroxenes in basic schists from the Nishiki-chô district.
I : Trend in the Black Jack sill (WILKINSON, 1957).
II : Trend in the Garbh Eilean sill (MURRAY, 1954).
III: Trend in the Skaergaard intrusion (BROWN, 1957; BROWN and VINCENT, 1963).

This examination is in harmony with the conclusion obtained from other petrochemical examinations on basic schists. From these chemical as well as mineralogical features, it may be concluded that the majority of basic schists of the Nishiki-chô district have been derived from rocks of the alkalic rock series.

IV. CONCLUDING REMARKS

In the metamorphic formations of the Nishiki-chô district, which belong to the Sangun metamorphic terrain in the Inner Zone of Southwest Japan, basic rocks accompanied by ultramafic rocks are well developed. This kind of association can be correlated with the initial magmatism of the geosynclinal phase, called the ophiolitic kindred (TYRRELL, 1955). Neither orogenic nor post-orogenic magmatisms as defined by TYRRELL (1955) and others can be recognized in this district. These basic rocks have been affected by regional metamorphism, named the Sangun metamorphism, to alter to greenschists mostly, accompanied by glaucophane schists. After MIYASHIRO's classification, therefore, the terrain belongs to the high-pressure intermediate group.

As to the genesis or mechanism of formation of the ophiolitic kindred rocks, there remain many puzzling problems not only in Japan but also all over the world. In the Sambagawa and the Sangun belts in Japan, it has hitherto been assumed that most basic metamorphic rocks have been derived from basic pyroclastic rocks and lavas, that being in harmony with their definite horizons of occurrence in the stratigraphy of metamorphic formations. In the Nishiki-chô district, however, their occurrence and structure suggest their intrusive origin, such as sills, injected in the geosynclinal phase into the formation of pelitic beds, which might have been weakly consolidated.

There are opinions about the genesis of ophiolitic magmatism in the geosyncline. One insists that the magmatism is a type of powerful submarine fissure-eruption (e.g. AUBOUIN, 1965), while the other regards it as the intrusive (e.g. THAYER, 1967). With regard to submarine volcanism, MCBIRNEY (1963) discussed theoretically, summarizing that explosive basaltic eruption accompanied by ash formation is not possible at depths greater than about 500 m and the quiet extrusion or intrusion of submarine lavas is rather likely to occur. In geosynclinal piles of sediments, flatly deposited and water-saturated at the initial stage of geosynclinal development, magmatism would have occurred either as the submarine eruption, pouring out of fissure-type vents, or injecting along the surface of stratification, when surfaces of discontinuity such as faults had not yet been formed.

The ophiolitic magmatism in the Nishiki-chô district may correspond mostly to the later case. Basic schists of sill-like form have specified features in common, that is, the main part of the mass, consisting of coarse-grained green rocks (type I), is bordered by pale-green, slightly schistose, fine-grained rocks (type II), which are fairly different in composition and fabrics from the main part of the body (Figs. 6, 7 and 8). The origin of type II rocks cannot be uniquely defined, but they represent the hybrid zone either of chilled margin or of altered pelites, heavily affected by metasomatism during regional metamorphism. The main part of the basic body, consisting of type I rocks, shows a significant variation of chemical composition, reflecting either magmatic differentiation within the original basic magma, or selective migration of certain elements during metamorphism. In a sill-like body, the Deai–Miyanokushi mass, about 250 m thick, the solidification index varies from about 35 near the margin to about 20 at the center (Fig. 11).

Based on the petrochemical characters of the basic schists along with the mineralogy of relic clinopyroxenes, most of the basic schists of the Nishiki-chô district may be regarded as derived from rocks of the alkalic rock series (Figs. 13, 14 and 15).

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