Jour. Fac. Sci., Hokkaido Univ., Ser. IV,
vol. 18, no. 4, Sept., 1978, pp. 509-520

RELICT CLINOPYROXENES IN THE MIKABU GREENSTONES, OSHIKA AND KOSETOKYO DISTRICTS, NAGANO PREFECTURE, CENTRAL JAPAN

by

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(with 5 text-figures, 2 tables and 1 plate)

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Abstract

Magma types and spilitization process of the metamorphosed greenstones (Mikabu greenstones) in the Oshika and Kosetokyo districts were examined on the basis of the chemical composition of rocks and relict clinopyroxenes. The alkali contents of the rocks are plotted in both alkaline and tholeiite basalt fields. However, most greenstones with high alkali contents have less TiO_2 and P_2O_5 than typical alkali basalts. One of the rocks carries the clinopyroxene with high Si and low Ti contents as in tholeiite basalts. These features may be interpreted as due to spilitization. It is suggested that most of the original rocks of the Mikabu greenstones of these districts, especially of Kosetokyo district, show an oceanic tholeiite affinity, though some an alkali basaltic affinity.

Introduction

Although the name Mikabu has been used for a long time among Japanese geologists the definition of which is not always clear. In this paper, "Mikabu greenstones" is used for the metamorphosed basic rocks occurring along the boundary between the Sambagawa and Chichibu Belts (Iwasaki, 1969), and the definition of the Sambagawa and Chichibu Belts in the Oshika-Kosetokyo district is same as used by Watanabe (1977).

The authors describe briefly the mode of occurrence of the Mikabu greenstones and relict clinopyroxenes, and discuss submarine volcanism that supplied source materials to the Mikabu greenstones in the Oshika and Kosetokyo districts.

Detailed geology and petrology in part of the districts were reported in Watanabe (1977) and Watanabe and Kawachi (1977).

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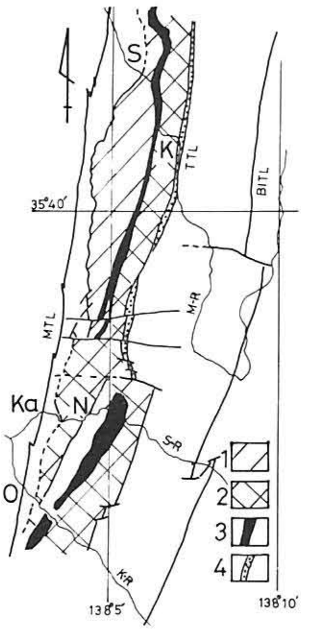
Mode of Occurrence of the Greenstones

Distribution of the Mikabu greenstones and associated ultramafic rocks in the Oshika-Kosetokyo district is shown in Fig. 1. In the western part of the district, crystalline schists of the Sambagawa Belt occur, whereas the rocks of the Chichibu Belt are located in the east.



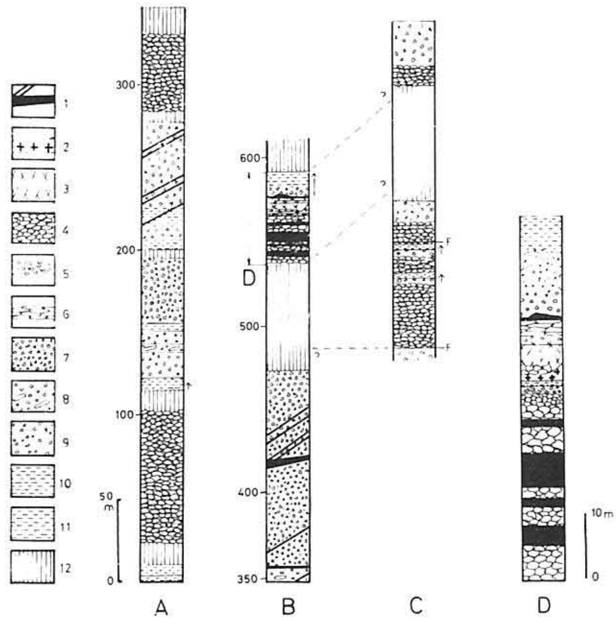


Fig. 1 (left) Distribution of the Mikabu greenstones in the Oshika-Kosetokyo district. 1: Mikabu greenstones (predominant area of basic schist) 2: Mikabu greenstones (massive rocks), 3: ultramafic rocks, 4: Todai formation (Lower Cretaceous) S: Sugishima, K: Kosetokyo, N: Nashihara, Ka: Kashio, O: Oshika, MTL: Median Tectonic Line, TTL: Todai Line, BITL: Butsuzo-Itokawa Tectonic Line, M-R: Mibugawa River, S-R: Siokawa River, K-R: Koshibugawa River

Fig. 2 (right) Columnar sections of the Mikabu greenstones across the Kosetokyo Gorge. 1: dyke or sheet, 2: gabbro, 3: massive lava, 4: pillow lava 5: brecciated pillow lava, 6: flattened pillow lava, 7: hyaloclastic breccia with poor matrix, 8: hyaloclastic breccia with lava tongue, 9: hyaloclastic breccia with abundant matrix, 10: hyaloclastic sandstone, 11: hyaloclastic siltstone, 12: no outcrop. Facing directions are shown by arrows. F: fault

The Mikabu greenstones are composed mainly of metamorphosed hyaloclastites, pillow lavas, and intrusive rocks with minor siliceous and scarce psammitic and pelitic rocks. As a whole, various types of hyaloclastites are predominant. Pillow lavas are common along the road crossing Kosetokyo Gorge, where a N-S trending serpentinite occurs at the western margin and greenstones with a NNE strike and about 45° dip to the east are widely distributed. Gradded bedding in the hyaloclastic sandstones* shows to be right-side-up. Rootless serpentinite blocks (each about 1000 m^3) are rarely found to be scattered in the greenstones and ten or more dykes are also found along this route. The greenstones along the Kosetokyo route are mainly metamorphosed hyaloclastic breccias and pillow lavas. The total thickness is over 650 m (Fig. 2). Under the microscope, original minerals and textures such as clinopyroxene, pseudomorph olivine, glass shard etc. are well preserved (Plate I). Glass shard has, for example, following composition; SiO_2 = 37, TiO_2 $\leqslant$ 1.0, Al_2O_3 = 20 – 21.5, FeO $\leqslant$ 7.5, MnO $\leqslant$ 5.5, CaO = 20.5 – 22, Na_2O = 0.1, and K_2O = 0.1 (wt.%), indicating that this is composed mainly of fine grained pumpellyite.

In the Oshika district, wehrlite (or wehrlitic serprntinite) and hornblendite (or hornblende gabbro) are widely distributed, and pillow structure is scarcely developed. Under the microscope weak schistose texture is common, and original texture is obscured although relict clinopyroxene and some brown amphibole are preserved.

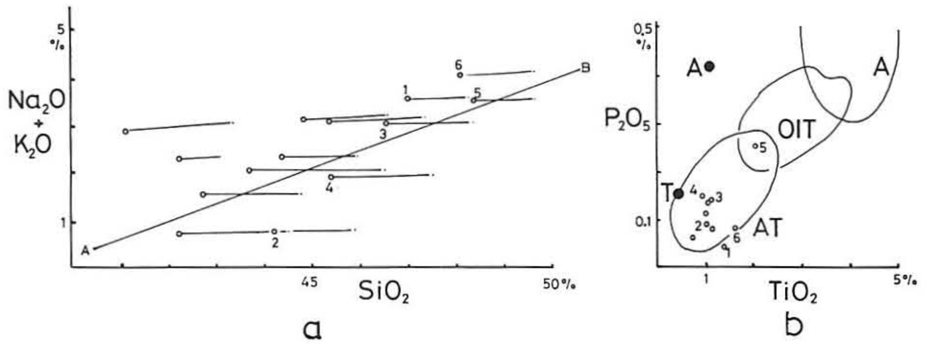


Fig. 3 SiO_2 – (Na_2O+K_2O) diagram (a) and P_2O_5 – TiO_2 diagram (b) for the lavas and intrusive rocks in the greenstones in the Oshika-Kosetokyo district (open circles).
a) A – B: boundary line between alkali and tholeiite rocks by Macdonald and Katsura (1964). Small solid circles show recalculated data excluding water.
b) A: alkali basalt, OIT: oceanic island tholeiite, AT: abyssal tholeiite (after Rodes, 1973) solid circles with T and A: tholeiite and alkali basalt of island arc, respectively. (Kuno, 1976)

* Definition and classification of hyaloclastites are based on a proposal by Kawachi et al. (1976)

The Mikabu greenstones have suffered Sambagawa metamorphism and the metamorphic minerals such as actinolite, pumpellyite, Na-amphibole, Na-pyroxene, epidote, chlorite, sphene, calcite, albite, minor quartz and opaque minerals occur.

Bulk chemical compositions of lavas and dykes of the greenstones are plotted in both high alkali tholeiite and alkali basalt fields. However, when recalculated to anhydrous compositions, more rocks are plotted in high alkali tholeiite field (Fig. 3a). TiO_2 content of these rocks are higher than the island arc tholeiite and P_2O_5 lower than average alkali rocks. SiO_2 ranges from 41% to 50% and Al_2O_3 is less than 17% (Table 1). SiO_2 and $Na_2O + K_2O$ in some greenstones decrease with increasing $H_2O^{(+)}$ (Watanabe, 1977). This indicates that the chemical composition of some greenstones are obviously affected by secondary alteration.

Table 1 Selected bulk chemical compositions and CIPW norms of the greenstones in the Oshika-Kosetokyo district.

	1	2	3	4	5	6
SiO_2	46.95	44.16	46.48	45.42	48.30	48.01
TiO_2	1.46	1.03	1.13	0.95	2.06	1.65
Al_2O_3	16.79	7.92	14.99	13.30	14.91	12.84
Fe_2O_3	4.47	3.55	2.78	2.20	1.98	3.73
FeO	7.67	9.08	7.26	8.98	9.67	8.37
MnO	0.11	0.14	0.16	0.18	0.21	0.71
MgO	6.09	17.69	7.31	8.66	5.09	7.79
CaO	9.94	10.95	12.66	12.98	9.91	8.91
Na_2O	3.36	0.53	2.98	1.72	3.26	3.79
K_2O	0.24	0.28	0.08	0.27	0.30	0.42
P_2O_5	0.04	0.09	0.14	0.15	0.25	0.08
H_2O^+	2.78	3.80	3.85	4.46	3.68	3.16
H_2O^-	0.14	0.24	0.02	0.28	0.10	0.46
Total	100.04	99.46	99.84	99.55	99.72	99.92

	1	2	3	4	5	6
or	1.50	1.73	0.49	1.68	1.85	2.58
ab	29.24	4.72	22.27	15.35	28.75	33.30
an	30.83	19.28	28.43	29.29	26.23	17.43
ne			2.17			
di	15.95	29.68	29.22	30.63	19.31	22.69
wo	8.21	15.49	15.06	15.70	9.73	11.66
en	5.05	11.04	9.32	9.20	4.71	7.06
fs	2.69	3.09	4.85	5.73	4.87	3.96
hy	3.60	17.05		5.14	13.07	0.42
en	2.35	13.33		3.17	6.42	0.27
fs	1.25	3.72		1.97	6.64	0.15
ol	9.27	19.99	10.64	12.27	3.12	14.53
fo	5.83	15.27	6.76	7.27	1.46	8.98
fa	3.44	4.72	3.87	4.99	1.66	5.55
mt	6.67	5.39	4.20	3.36	2.99	5.61
il	2.85	2.05	2.24	1.90	4.08	3.25
ap	0.10	0.20	0.34	0.37	0.60	0.19
total	100.00	100.03	100.00	99.99	100.00	100.00

1: 72805, schistose meta-basalt,Koshibugawa River.
2: 90310, schistose meta-gabbro, Shiokawa River.
3: 7472101, chromian pyroxene-bearing fine meta-diabase, Kosetokyo.
4: 74102016, meta-basalt, Takaiwa, north of Kosetokyo.
5: 74721905, meta-basalt, Kosetokyo.
6: 7471901, meta-basalt, Kosetokyo. Sector-zoned pyroxene in this rock is analyzed (Plate ld).
Analyst: 1 & 2, T. Watanabe; 3-6, Mineral and Coal Institute, Tokyo.

Chemical Composition of Relict Clinopyroxene

Relict clinopyroxene is common in the greenstones. Analysis was done using EPMA of Geological Survey of Japan, Government Industrial Development Laboratory, Hokkaido, and Faculty of Engineering of Hokkaido

University. EPMA of Geological Survey of Japan is computer controlled (Okumura, Soya and Kawachi, 1974). Correction of data was done by the method of Sweatman and Long (1969) and Bence and Albee (1968).

As shown in Fig. 4, Al and Ti contents of the clinopyroxene have wide ranges and plot in both alkali and tholeiite fields of Maruyama's classification (1976). The clinopyroxenes are classified into eight groups (*a* – *h*) on the basis of their mode of occurrence (Fig. 4).

Group *a* clinopyroxene: Clinopyroxene having the highest Ti content was found in a doleritic fragment in hyaloclastic breccia from upstream of Shiokawa River. Group *a* clinopyroxene was also found in an aphanitic meta-basalt showing deformed pillow structure with a few vesicles upstream of Shiokawa River. The clinopyroxene occurs as micro-phenocryst or in the groundmass, subhedral to granular or tabular in shape, and less than 0.1 mm in size.

Table 2 Selected EPMA chemical analyses of group *a* to *h* relict clinopyroxenes. Clinopyroxene marked f′ is of Group *f* without sector zoning.

	a	a	b	c	d	e	f	f	f'	g	h	h
sample	No.81906	7472004	50801	92416	81905	72813	7471901	7471901	7471901	7472101	7472612	90504
SiO_2	48.40	49.54	48.97	50.28	50.38	50.60	50.65	52.44	52.06	48.95	50.74	47.90
TiO_2	1.41	1.23	0.64	0.89	1.17	0.61	0.69	0.48	0.51	1.04	0.89	1.12
Al_2O_3	4.23	4.46	5.09	4.88	4.43	2.45	4.74	2.25	3.17	4.59	2.18	5.47
Cr_2O_3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.78	n.d.	n.d.
FeO	10.70	7.21	5.95	6.32	8.82	7.87	6.78	7.10	6.27	6.91	9.88	9.58
MnO	0.11	0.21	0.05	0.10	0.13	n.d.	0.14	0.19	0.09	0.15	0.29	0.27
MgO	14.50	15.51	17.11	15.01	13.47	16.30	15.67	17.03	16.45	15.34	15.08	14.40
CaO	20.80	21.20	21.55	21.84	21.20	22.30	20.64	20.10	21.42	22.25	19.92	20.50
Na_2O	0.32	0.25	0.69	0.27	0.49	n.d.	0.24	0.21	0.22	0.25	0.33	0.52
K_2O	0.00	0.01	0.01	0.02	0.01	n.d.	0.00	0.00	0.00	0.00	0.01	0.01
Total	100.47	99.62*	100.06	99.61*	100.09*	100.13	99.55**	99.80**	100.19**	100.26**	99.33*	99.77
Si	1.82	1.845	1.82	1.863	1.876	1.88	1.874	1.933	1.911	1.820	1.911	1.80
Al	0.18	0.155	0.18	0.137	0.124	0.11	0.127	0.067	0.090	0.180	0.089	0.20
Al	0.01	0.041	0.04	0.076	0.071	-	0.080	0.030	0.048	0.021	0.008	0.05
Cr	-	-	-	-	-	-	-	-	-	0.023	-	-
Ti	0.04	0.034	0.02	0.025	0.033	0.02	0.019	0.013	0.014	0.029	0.025	0.03
Fe	0.34	0.225	0.18	0.196	0.0275	0.25	0.210	0.219	0.193	0.215	0.311	0.30
Mn	0.00	0.007	0.00	0.003	0.004	-	0.004	0.006	0.003	0.005	0.009	0.01
Mg	0.81	0.861	0.94	0.829	0.748	0.90	0.864	0.935	0.900	0.850	0.846	0.81
Ca	0.84	0.846	0.86	0.867	0.846	0.89	0.818	0.794	0.842	0.886	0.804	0.83
Na	0.02	0.018	0.03	0.020	0.035	-	0.017	0.015	0.016	0.018	0.024	0.04
K	0.00	0.000	0.00	0.001	0.001	-	0.000	0.000	0.000	0.000	0.001	0.00
	4.06	4.032	4.06	4.016	4.012	4.06	4.013	4.013	4.015	4.047	4.028	4.07
F/M	0.29	0.207	0.16	0.191	0.269	0.22	0.196	0.190	0.189	0.202	0.269	0.27

* analysis by T. Watanabe. ** analysis by M. Yuasa. The rests were analysed by Y. Kawachi.
F/M: Fė/(Mg+Fe) ratio

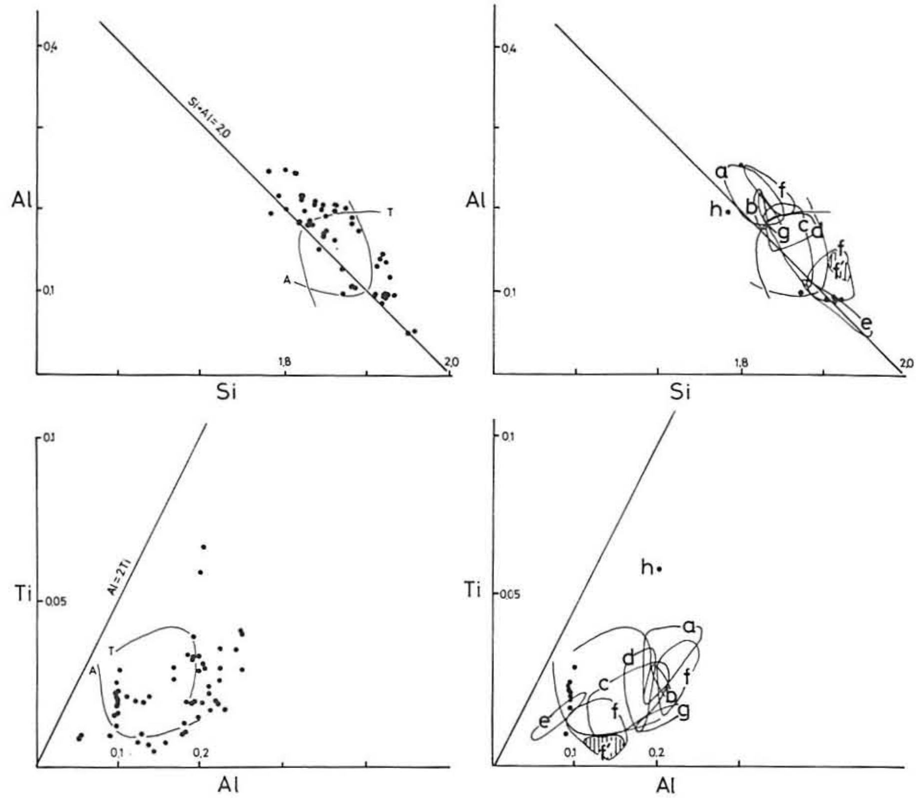


Fig. 4 Al – Si diagram and Ti – Al diagram of relict clinopyroxene. The upper part of the line A is the field of alkali basalt and the lower part of the line T is that of tholeiite (Maruyama, 1976). The area shown by f′ is the field of the larger phenocrystic clinopyroxene without sector zoning.

Group *b* clinopyroxene: Subhedral phenocryst, 0.2 – 0.5 mm in size, occurs in fine-grained meta-basalts with subophitic texture and abundant in varioles.
Group *c* clinopyroxene: This is found in brown amphibole-bearing pyroxene meta-basalts which sometimes occurs as pillow lavas or tongues in Nashihara. The clinopyroxene is euhedral to subhedral phenocryst, 0.2 – 1 mm in size. Brown amphibole (TiO_2 = 2%) is formed around some clinopyroxenes. Judging from the original mineral assemblage, the rocks carrying the clinopyroxene of this group is alkalic.
Group *d* clinopyroxene: Medium-grained meta-basalts with subophitic texture contains Group *d* clinopyroxenes. They are subhedral to granular or columnar phenocrysts, 0.2 – 1 mm in size. Saussuritized plagioclase in rarely observed in these basalts.
Group *e* clinopyroxene: Clinopyroxene of this group occurs in saussuritized diabases consisting mainly of clinopyroxene phenocryst (1.5 mm in max. size)

and saussuritized plagioclase with subordinate amount of metamorphic minerals such as actinolite, chlorite, epidote, etc. in upstream of Koshibu-gawa River.

Group *f* clinopyroxene: Aggregates of chlorite which is pseudomorph after olivine often occur in pillow lavas at Kosetokyo Gorge and its southern

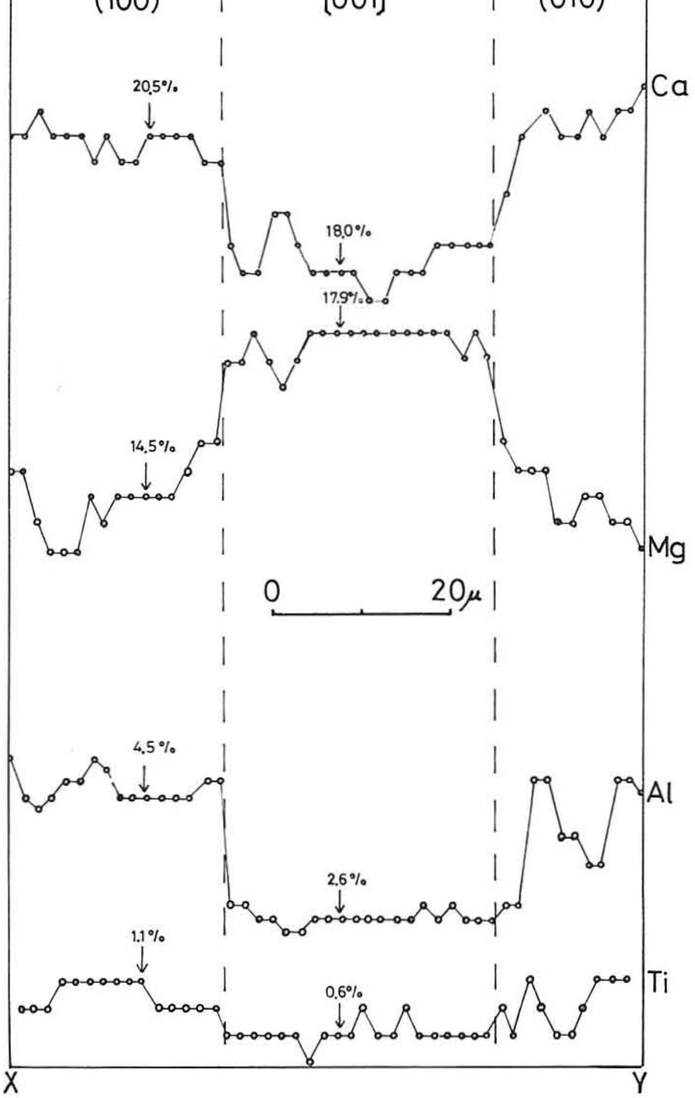


Fig. 5 Semi-quantitative step-scan analysis for Ca, Mg, Al, and Ti contents of the microphenocrystic clinopyroxene with sector zoning. Contents are shown by weight percent of oxide. (Analyst M. Yuasa)

extensions. In these pillow lavas, phenocrysts of albitized plagioclase and clinopyroxene, 0.5 – 1 mm in size, columnar to granular and euhedral to subhedral, are also observed. Swallow-tail plagioclase and dendritic clinopyroxene are also found in groundmass. Microphenocrystic clinopyroxene of this group shows marked sector zoning (Plate 1d). (100) and (010) sectors are richer in Al_2O_3, TiO_2, FeO and CaO than [001] sector (Fig. 5). Sectors rich in Al_2O_3 and TiO_2 are plotted in the alkali rock field whereas other sectors in the tholeiite field of Maruyama (1976). Large phenocrystic clinopyroxene without sector zoning (f′ in Fig. 4) in the same rock is plotted in the tholeiite field, although its host rock falls in the alkali rock field of SiO_2 – $Na_2O + K_2O$ diagram of Macdonald and Katsura (1964). This contradiction, which is recognized in so far as using the Maruyama's classification, may have been due to spilitization (Vallance, 1974).

Chromian pyroxene (Group *g*) is found in meta-diabases of pillow lava at Kosetokyo Gorge. The chromian pyroxene is subhedral, granular or columar (0.1 – 0.5 mm in size) and shows a distinct pleochroism in the margin (x′ = pale yellow, z′ = pale light green; Cr_2O_3 = 1.60%), while pleochroism is faint in the core (Cr_2O_3 = 0.53%). The diabase is plotted near the boundary between alkali and tholeiite fields of SiO_2 – Na_2O+K_2O diagram.

Group *h* clinopyroxene: Clinopyroxene of this group in gabbros varies considerablly in Al and Ti contents in each gabbroic body. Clinopyroxene rich in Si was found in the gabbro at the middle stream of Shiokawa River and in gabbroic xenolith included in diabase at Koshibu-gawa River.

Some Discussions and Summary

It has been pointed out that most original rocks of the greenstones so far known are derived from tholeiitic basalts (Suzuki et al., 1971; Sugisaki and Tanaka, 1971; Sugisaki, 1977), though some basalts with high alkali contents are also reported (Sugisaki, 1977). Inverted pigeonite is reported from the Mikabu greenstones in the eastern Shikoku (Nakayama et al., 1973), indicating that the host basalt belongs to tholeiite series.

Chemical composition of Ca-rich pyroxene is controlled by magma type of host rocks (Kushiro, 1960; Le Bas, 1962; Hashimoto, 1965) as well as by silica activity (Gibb, 1972; Yagi and Onuma, 1974). Kawachi and Watanabe (1972) reported the chemical compositions of relict clinopyroxenes in the Mikabu greenstones from the Oshika district and stated that the compositions correspond to those of clinopyroxene of both tholeiite and alkali rocks of Le Bas' diagram. Recently, Maruyama (1976) re-examined Le Bas' classification and proposed a revised relationship between chemical composition of Ca-rich pyroxene and host magma type. This relation is applied only to the phenocrystic clinopyroxene with high Mg content (Fe/(Fe+Mg) < 0.25) in undifferentiated basalt. Takasawa and Hirano (1977) pointed out that phenocrystic magnesian clinopyroxene in tholeiite basalt is rich in Al and Ti and claimed that Maruyama's classification is not complete. However, their discussion was made on the basis of quenched clinopyroxenes as well as phenocrystic ones. Since quenched clinopyroxenes are not equilibrium products, their discussion may not be complete. Nagao (1977) also showed that the classification of Maruyama may fail in some cases.

Secondary chemical change of deep-sea basalt or pillow lava is well known (Hart, 1970; Miyashiro et al., 1971 etc.). Therefore estimation of magma type of the Mikabu greenstones based on bulk chemical composition or relict clinopyroxene composition must be carefully examined.

Judging from the $SiO_2 - Na_2O+K_2O$ diagram and relict clinopyroxene compositions in the Oshika-Kosetokyo district, the greenstones correspond to both alkali and tholeiite basalts. However, P_2O_5 contents of the greenstones are not so high and show some affinity to tholeiite (Fig. 3b). TiO_2 contents of the greenstones are similar to those of the abyssal tholeiites, though the contents are slightly low (Fig. 3b). Taking into account subtraction of SiO_2 and addition of Na_2O+K_2O which are characteristic chemical change in secondary alteration, the greenstones under discussion may correspond mostly to tholeiite basalts in oceanic area. The contradiction between bulk chemical composition (high alkali contents) and relict clinopyroxene compositions (high Si and Low Ti contents, tholeiitic?) of the group *f* as mentioned earlier suggest secondary chemical change (spilitization). Lavas in the greenstones are low in Al_2O_3 content when the rocks have low FeO^*/MgO ratio. This does not fit into the characteristics of the abyssal tholeiite (Shibata, 1976). Basalt with low Al_2O_3 and high MgO was dredged from Mid-Oceanic Ridge (Muir and Tilley, 1964), and the basalt similar in composition to that of the Mikabu greenstones was also found in the oceanic area (Sugisaki, 1977). Accordingly, most of the Mikabu greenstones in these districts, especially in Kosetokyo, are likely to have derived from oceanic tholeiites. Later alteration affected their SiO_2 and alkalis contents during sedimentation and metamorphism. Alkali basalts also exist in some places.

Acknowledgement

This paper is dedicated to Emeritus Professor Kenzo Yagi at his retirement from Hokkaido University in April of 1978. He has encouraged us during our study for which we are grateful. We (especially T.W.) wish to express our

FeO^* = total iron expressed as FeO

thanks to Professor Y. Katsui and Dr. K. Onuma for their critical reading of the manuscript. We gratefully acknowledge the assistance on EPMA analyses by the following persons, Messrs. K. Okumura and T. Soya (Geological Survey of Japan), Drs. S. Suzuki and S. Sayama (Government Industrical Development Laboratory, Hokkaido) and Mr. H. Kuwahata (Technology Department, Hokkaido University). Dr. M. Inomata of Tokyo University of Education kindly supplied us a rock specimen. Mrs. S. Yokoyama typed kindly the manuscript.

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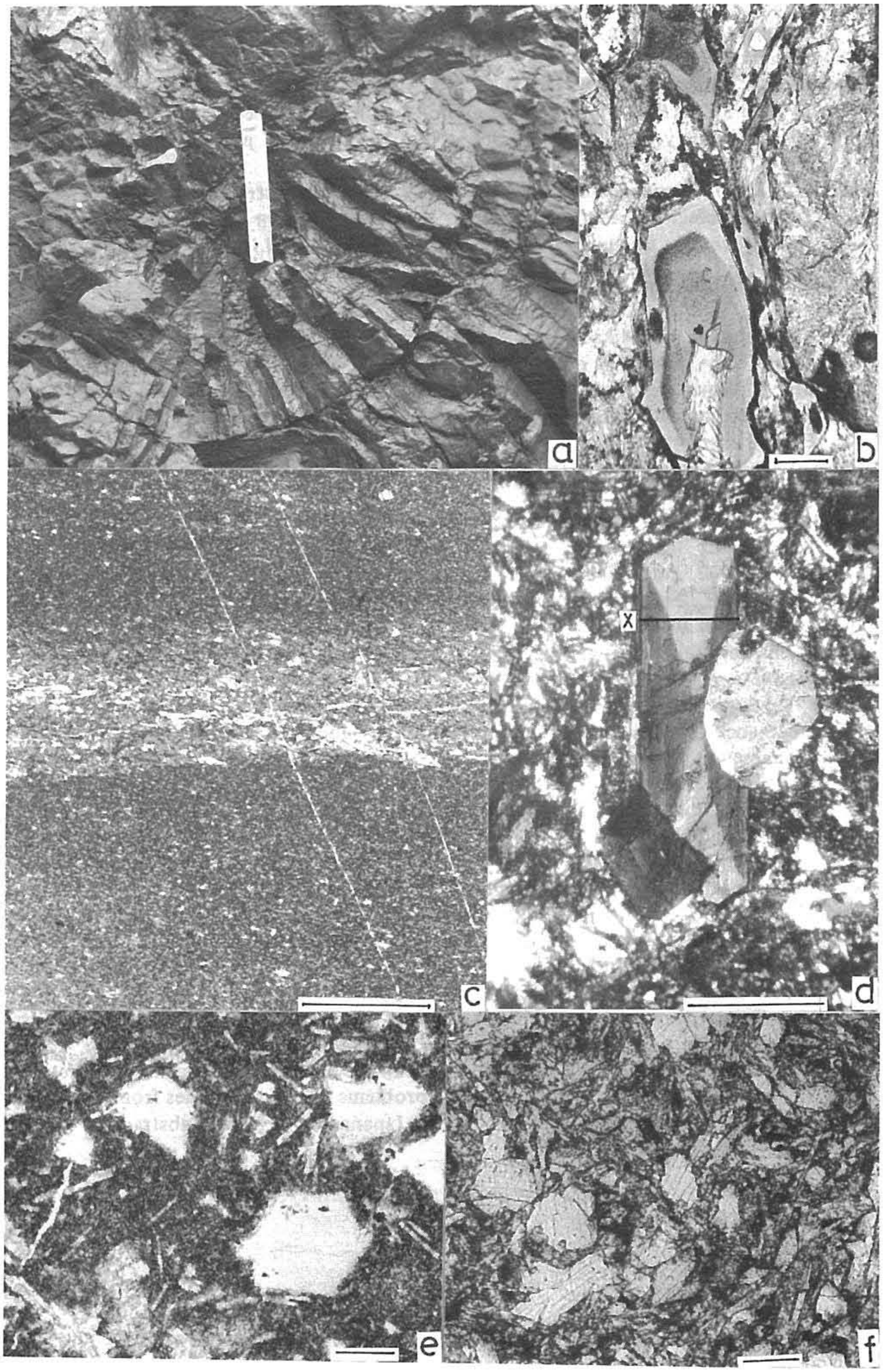
Explanation of Plate 1

a: Pillow lava with radial joints, Kosetokyo.
b: Altered glass shards having similar composition of pumpellyite, Kosetokyo. scale 0.1 mm.
c: Fine gradded bedding in a hyaloclastic sandstone, Kosetokyo. scale 0.5 cm.
d: Analysed sector zoning of a clinopyroxene, Kosetokyo (see Fig. 5, sample number 7471901). scale 0.1 mm.
e: Chlorite aggregates showing pseudomorph after olivine in a meta-basalt, Kosetokyo. scale 0.1 mm.
f: Chromian pyroxene in a fine meta-diabase, Kosetokyo (sample number 7472101). scale 0.1 mm.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(Received on October 31, 1977)